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THE ROLE OF SURFACE INSTABILITY IN ELECTRICAL DISCHARGES FROM DROPS OF ALCOHOL AND WATER IN AIR AT ATMOSPHERIC PRESSURE.

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ABSTRACT.

A study of previous work on discharges from charged attached drops and from uncharged drops falling in electric fields shows that the surface electric intensities at these drops, when the discharges begin, satisfy the theoretical relations for surface instability. Glow discharges, if initially present, are conditioned by the surface deformation arising from instability. Experiments are described that indicate that the highly charged droplets ejected by an alcohol surface may have mobilities not much below those of normal air ions while such droplets coming from a water surface may have mobilities even greater than those of air ions. Calculations, by Stokes' Law, show such large mobilities for both kinds of drops to be possible. Further experiments show that under certain conditions the whole discharge current from an alcohol drop is carried solely by droplets of the liquid, resulting from surface instability, and under more restricted conditions the same may be true for a water drop.

Rayleigh showed [1] that the surface of an isolated spherical drop of liquid becomes unstable if its potential V, in electrostatic units, is increased beyond that given by the relation

$$V = \sqrt{16\pi a T}, \qquad (1)$$

"a" being the radius of the drop in centimeters and T its

[1] Lord Rayleigh, *Phil. Mag.* (5), **14**, 184 (1882).

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surface tension in dynes per centimeter. The limiting value of the electric intensity, f, at the surface of the drop for instability is then given by

$$f\sqrt{a} = \sqrt{16\pi T}. \qquad (2)$$

Some years ago [2, 3] a study was made of electrical discharges from hemispherical drops of liquid protruding from the ends of small glass tubes, as a rule under 1 millimeter in diameter. In air at atmospheric pressure, the surfaces of these drops usually became unstable before a potential was reached that was sufficient to initiate a self-sustained discharge, and fine threads of liquid were pulled from the surfaces of the drops. The instability potentials were determined for seven different liquids differing widely in their surface tensions, a single tube of radius 0.025 centimeter placed 1.5 centimeters from a plane being used throughout the measurements. The results obtained could be correlated by the relation [3]

$$V = \sqrt{140aT}. \qquad (3)$$

This relation is found to be identical with equation (1), when account is taken of the experimentally determined fact [4] that the field at the end of a charged hemispherical drop under the conditions of the experiments is but sixty per cent. of its value on an isolated spherical drop charged to the same potential.

In another series of experiments [2] the radius of the tube was varied between 0.0146 and 0.0543 centimeter and water at an average temperature of 22° C. was the only liquid used; the distance between the point and plane being again 1.5 centimeters. The electric intensity at the surfaces of the hemispherical drops was measured by a hydrostatic method at the moment when a galvanometer in the circuit ceased to indicate a current. At the time, it was thought that an agitation of the liquid surface which accompanied the discharges, but which was present only in initial stages of positive currents, was caused by the action of the discharge itself.

[2] J. Zeleny, *Phys. Rev.*, **3**, 69 (1914).
[3] J. Zeleny, *Proc. Camb. Phil. Soc.*, **18**, 71 (1915).
[4] Reference 2, p. 74.

Later [3, 5] it was discovered that the discharge was actually initiated by the oncoming of surface instability, the requisite potential for which for water drops in air at atmospheric pressure is nearly the same, for drops of the small size used, as that required for starting glow discharges. The values of the electric intensities obtained were thus in reality the limiting values for surface instability.[6] The results of the experiments referred to were expressed by the relation, $f\sqrt{a} = 56.9$, a form identical with equation (2), in which, however, the value of the constant is 60, for $T = 72$. Considering the difficulties inherent in them, the two sets of experiments, one in which T was varied and the other in which "a" was varied, are thus seen to be in fairly good agreement with theory.

In order to get results more directly applicable to rain drops in thunderstorms, Wilson and Taylor [7] and Macky [8] carried out important experiments with hemispherical soap bubbles resting on earthed liquid surfaces, and Nolan [9] and Macky [10] with uncharged water drops falling through uniform electric fields. Their concordant results show that the smallest external field F, expressed in volts per centimeter, in which a falling drop will be disrupted is related to the radius of the drop, "a," by the equation, $F\sqrt{a} = 3875$. When F is taken in electrostatic units per centimeter the constant becomes 12.92.

It is of interest to determine whether this relation obtained for larger drops under quite different conditions from the earlier experiments is also in accord with the theoretical requirements for instability as given by equation (2), in order to find out whether instability conditions alone governed

[5] J. Zeleny, *Phys. Rev.*, **16**, 108 (1920).

[6] In reference 2 on p. 81 it was stated that contrary to what is observed with metal points, the potentials at which discharges from liquid points begin were found to be the same for positive and negative discharges. As the potentials measured turned out, later, to be those requisite for the initiation of surface instability, they naturally were independent of the sign of the charge used. Some authors have failed to note that the first statement was nullified by the subsequent discovery.

[7] C. T. R. Wilson and G. I. Taylor, *Proc. Camb. Phil. Soc.*, **22**, 728 (1925).

[8] W. A. Macky, *Proc. Camb. Phil. Soc.*, **26**, 421 (1930).

[9] J. J. Nolan, *Proc. Royal Irish Acad.*, **37**, A, 28 (1926).

[10] W. A. Macky, *Proc. Royal Soc. A*, **133**, 565 (1931).

the disruption of the falling drops, and so preceded, as was supposed, the concomitant gaseous discharge whose presence was manifested by the luminous effects which uniformly accompanied the disruption of the drops.[10] In making the comparison, account must be taken of the fact that the falling drops were already considerably elongated by the field when their disruption took place, so that both the curvature of the surface and the field, f, at the elongated ends had values that differed from those of a spherical drop similarly situated. Macky [10] states that in his experiments, at the onset of disruption, the length of the drops was three to four times as great as their diameter. Using these degrees of elongation as a basis for computation, and assuming, as a first approximation, that the elongated drops were prolate ellipsoids of revolution, the radii of curvature at the pointed ends have been calculated in terms of the radii of spheres of equal volume, and the fields at these ends have been obtained in terms of the uniform external field in which the drops fell, by means of the relation

$$f = F \cdot \frac{\frac{\epsilon^3}{1 - \epsilon^2}}{1/2 \log \left(\frac{1 + \epsilon}{1 - \epsilon} \right) - \epsilon}, \qquad (4)$$

where ϵ is the eccentricity of the generating ellipse of the ellipsoidal drop. Substituting the values thus obtained into the equation, $F\sqrt{a} = 12.92$, the value of the product $f\sqrt{a}$ comes out equal to 57, when the length of the drop is taken to be three times its diameter, and 68, when the length is four times the diameter. Since for instability the theoretical value of this product, i.e. 60, lies between these two numbers, added support is given to the conclusion drawn by the above authors that water drops falling in a uniform field become unstable before glow discharges start from their surfaces. Had the gaseous discharge commenced first its presence would have changed the strength of the field at the liquid surfaces and the instability relation would not have been found applicable.

That instability controlled the disruption process is further evidenced by Macky's [10] experiments in which the

pressure of the air surrounding the falling drops was varied. He found that the least field in which a discharge from the drops occurred was independent of the gas pressure, down to a pressure of 26 centimeters of mercury. Such independence of pressure is expected of instability effects but not of glow discharges. Disruption of the drops was indeed always seen here too to accompany the discharge and this disruption must in fact have started to take place before the discharge commenced, and must have been more and more advanced when the discharge began as the pressure used was higher and higher.

A question arises whether at atmospheric pressure a gaseous discharge always accompanies the disruption of a liquid surface made unstable by a high electric field. At higher pressures surface instability may occur without a glow discharge just as the reverse is found to be true at pressures somewhat below that of the atmosphere.[3, 5] In working with drops of ethyl alcohol in air at atmospheric pressure, I found that for a voltage only slightly greater than that necessary for making the surface unstable the drop at the end of a small tube assumed a nearly conical form, and a continuous thread of liquid issued from the apex of the cone. This filament quickly broke up into innumerable and individually invisible droplets that had the appearance of a colored mist when viewed under strong side illumination.[11] A stream of air from a foot bellows, directed along the surface of a divided plate placed below the discharging point, prevented the carriers from reaching the upstream half of the plate under conditions where it was assumed (as now appears erroneously) that normal air ions would suffer but little deflection. Accordingly it was concluded [3] that here the droplets of alcohol carried all of the charge that passed to the plate below the point. Macky [9] interprets my conclusions as applying also to discharges from water surfaces but such was not intended to be the case since similar experiments had not at that time been done with water.

Nolan and O'Keeffe [12] undertook to determine, for discharges from liquid surfaces, whether the charge is carried

[11] J. Zeleny, *Phys. Rev.*, **10**, 1 (1917).

[12] J. J. Nolan and J. G. O'Keeffe, *Proc. Roy. Irish Acad.*, **39**, 21 (1929).

mainly by drops of liquid or by gaseous ions, by measuring the mobility of the carriers by means of Chattock's method. They used water and several alcohols for their points and found in all cases that the mobilities of the carriers corresponded closely to those of gaseous ions, and concluded that the ordinary small air ions are the actual carriers. This conclusion is not necessarily in conflict with my own for ethyl alcohol. My experiments were done in the range of small currents with potentials only a little above the minimum required for producing surface instability and under liquid pressure conditions for which the discharging surface assumed the conical form, which has been described above. On the other hand, Nolan and O'Keeffe used much larger fields and currents.

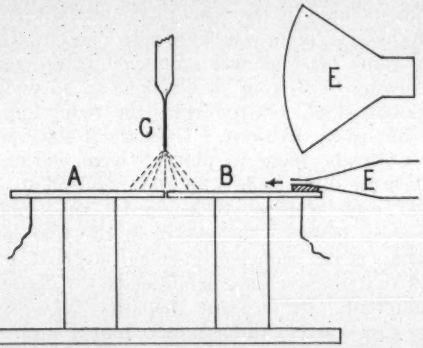
There is no question but that the potential required to produce instability in a hemispherical surface of ethyl alcohol, such as was used here, is much smaller than is requisite for starting a self-sustained discharge from a surface of the same form; but there is a question whether in practice a potential which just makes such a surface unstable also suffices always to initiate a gaseous discharge, owing to the enhancement of the electric field at the surface by the deformation arising from the instability. Obviously, while the term potential is often used, as here, in connection with similar problems, because its numerical value can be more easily given, the electric field is actually the determining factor.

EXPERIMENTS WITH ETHYL ALCOHOL.

It seemed desirable therefore to repeat and extend the experiments which were mentioned above in which it was found that under certain conditions the carriers of the charge passing between an alcohol point and a collecting plate could be prevented from reaching the upstream half of this plate by a moderate air blast directed along the surface of the plate. Accordingly two brass plates, A and B, 5 centimeters square, were mounted on insulating pillars with two edges 1 millimeter apart, as shown in Fig. 1. The discharge point, C, was usually placed directly above the space between the plates, of which B was joined to earth through a galvanometer and A was earthed directly. For further details of the liquid

point apparatus reference is made to previous papers.[2, 3] Instead of simply blowing the air by a foot-bellows from the end of a rubber tube, as was done previously, there was now used a flat metal nozzle E, with an opening 2×48 millimeters, rigidly fastened to the plate B; and the air was supplied to the nozzle from the pressure mains of the laboratory, a manometer being inserted in the air line to make it possible to keep the air stream constant. Attention was chiefly directed to making a comparison of the effect of a given blast upon the current flowing to B when the discharge point was emitting droplets of liquid with the effect of the same blast

FIG. 1.



Apparatus for comparing mobilities of ions by deflecting paths by a transverse stream of air.

upon the current from a metal point, where no droplets are present.

It will suffice merely to give some typical results obtained with alcohol when the tube, C, had a radius of 0.28 millimeter and was placed centrally 9 millimeters above the slot between A and B. The potentials to which the point was charged were all within the range where the alcohol meniscus assumed a conical form with a thread of liquid issuing from its apex.

A given blast from E reduced the current reaching the plate B from 15.5 divisions to 1.5 divisions (1 division

$= 1.9 \times 10^{-9}$ amperes throughout this paper) when the point was kept at a potential of + 3,000 volts; and from 30 divisions to 4 divisions for a point potential of + 3,250 volts. The brass point used for making the comparison had a rounded end of 0.095 millimeter radius and was 9.5 millimeters from the plates. The metal point had to be of a smaller size than the liquid one to permit the use of approximately the same potentials for both points, so that the velocities of the normal air ions would be the same in the two cases. The starting voltages for glow discharges from metal and liquid points of the same size are essentially alike,[5] and hence if a gaseous discharge started at all from the above alcohol point for the potentials used, it only did so after the meniscus had become pointed by the onset of the unstable condition.

When the brass point was charged to a potential of + 3,000 volts the same blast as was employed before reduced the current flowing to *B* from 70 divisions to 28 divisions; and with a potential of + 3,100 volts the reduction was from 105 divisions to 44 divisions. Thus about sixty per cent. of the ions normally going to plate *B* were deflected by the blast across the dividing line for the metal point, and about ninety per cent. were so deflected for the alcohol point. The difference between the effects in the two cases, while considerable, is not sufficiently great but that it must be concluded that the average mobilities of the carriers are not widely different. In fact the disparity between the two mobilities can scarcely differ much from a ratio of two or three to one.

It has been assumed, generally, that if the carriers of the charge from the liquid point were drops of liquid their mobilities would be exceedingly small. This is, however, not necessarily the case owing to the comparatively large charges carried by these drops. At present, it is not possible to calculate at all accurately the mobilities of the drops since both their sizes and charges are unknown. A rough estimate of their size was previously obtained [3] from measures of the volume of liquid ejected from the meniscus in a given time and from the total charge transferred in that time, on the basis of certain assumptions made regarding the potential contributed to the drops by their own charges. This esti-

mate gave a radius of only 10^{-5} to 10^{-4} centimeter. More recently [11] the filament from which the drops are formed has been found to have a radius of approximately 2×10^{-4} centimeter. The larger set of drops resulting from the breaking up of such a cylindrical filament should have radii somewhat greater than that of the filament itself. The appearance of coronal colors in the cloud of drops under strong illumination is also an indication [13] that the drop size lies between 10^{-3} and 10^{-4} centimeter.

Mobilities of carriers of these sizes may be computed in terms of their charges by means of Stokes' Law for the resistance offered to a sphere when moving through a viscous medium, adding Cunningham's correction term for making the law applicable to spheres whose radii are not large in comparison to the mean free paths of molecules of air. The mobility, v, in centimeters per second in a field of one volt per centimeter comes out,

$$v = q\left(1 + \frac{0.817 \times 10^{-5}}{a}\right) \Big/ 1.02a. \qquad (6)$$

The largest charge which a drop of any given size may carry without disruption may be found by means of equation (1). The maximum charges thus obtained for three different sizes of drops, both of alcohol and of water, and the mobilities in the above units computed for them by equation (6) are given in Table I. For fields of the magnitude used, gravity

TABLE I.

Radius of Drop.	q for Water.	v for Water.	q for Alcohol.	v for Alcohol.
10^{-5} cm.....	1.9×10^{-6} e.s.u.	.35	1.12×10^{-6} e.s.u.	.21
10^{-4}.....	6×10^{-5}	.64	3.54×10^{-5}	.38
10^{-3}.....	1.9×10^{-3}	1.88	1.12×10^{-3}	1.11

forces on the droplets are negligible relative to the electrical forces. The values of the mobilities thus found for alcohol are of the right order of magnitude, especially for the two larger sizes. But could charges as large as those given in the table be obtained by the drops, under the conditions of the

[13] C. Barus, *Am. Jour. Sci.* [4], **24**, 309 (1907).

experiments in question, from the parent meniscus which was kept at a potential of 3,000 volts? Now a sphere of radius 10^{-3} centimeter if placed in contact with a sphere of 0.028 centimeter radius charged to 3,000 volts would acquire a charge of 0.6×10^{-3} e.s.u., which is over half of the q value given in the table for alcohol. In the actual experiments where the drops were formed from a filament extending out several diameters from the apex of a conical surface the charges assumed by the drops must have been larger than for the case considered, of two spheres in contact; unless, as seems unlikely, the space charge of the drops in the field exerts a controlling influence at the place of drop formation. The decrease of size of these small drops by evaporation may also help to enhance their mobility.[14]

These considerations show that the alcohol drops in question may have mobilities not much below those of air ions, and hence mobility and blowing experiments alone cannot at present determine whether the charges in these experiments are carried mainly by gas ions or solely by drops of the liquid.

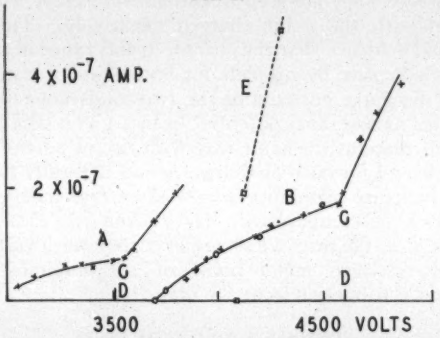
Further evidence on the subject was obtained by placing the point C, Fig. 1, over the center of plate A and measuring the variation of the current flowing to this plate with the potential of the point, in the absence of an air blast. The end of the point was subsequently observed in the dark through a low power microscope to determine the smallest voltage at which any luminous effects were visible. Luminosity, under these conditions, is taken to be a sure sign of the presence of a self-sustained discharge. Negative potentials were used both because glow discharges begin at lower potentials for negative currents from fine points than do positive currents, and because the luminosity attending the negative currents is confined to a smaller volume and has a greater intrinsic brightness than does that of positive currents, and hence is

[14] The condition that the sum of the surface and electrical energies should be a minimum for an isolated drop carrying a constant charge and undergoing evaporation gives, curiously enough, the same relation between V and a as appears in equation (1). A charged drop evaporates down to a certain size, determined by the above relation, when surface instability causes it to disrupt. Each fragment, large or small, in turn evaporates until it too becomes similarly disrupted, and so on.

visible with smaller currents. The data for curve *A* of Fig. 2 were obtained with an alcohol point of 0.28 millimeter radius placed 1.03 centimeters above the plate, and for curve *B* the radius of the point was 0.46 millimeter and its distance from the plate was 1.50 centimeters. The ordinates represent currents corresponding to potentials shown as abscissas.

Each curve shows a break at *C*, indicating that quite different laws of discharge apply to the two portions of the curve. During the observations for the lower portion of the curve the alcohol meniscus had the steady conical form, previously described, with a liquid jet issuing from its apex,

FIG. 2.



Variation with voltage of current from an alcohol point. Curve *A*. Radius of point, 0.28 mm. Distance to plate, 1.03 cm. Curve *B*. Radius of point, 0.46 mm. Distance to plate, 1.50 cm. Curve *E*. Metal point of radius, 0.20 mm. Distance to plate, 1.50 cm. Luminous effects were first observed at voltage *D*.

and for potentials beyond the break, *C*, the surface became somewhat agitated. The potentials at which luminosity at the point first appeared with rising currents and disappeared with diminishing currents are marked by the line *D* in each case. These potentials are seen to correspond closely with those at the breaks, *C*, in the curves. Moreover, the currents flowing at these potentials are larger than the minimum currents for which luminosity attending a self-sustained gaseous discharge can be observed with the eye.[15]

[15] J. Zeleny, *Phys. Rev.*, **24**, 255 (1924).

The most simple explanation of these results appears to be that for potentials below *C* the discharge current was carried solely by drops formed from the liquid jet issuing from the apex of the meniscus, whereas for potentials above *C* there was present in addition a self-sustained discharge through the gas. The light seen had the form of a short brush and was situated at or just above the tip end of the conical meniscus. Once, the brush appeared at the side of the cone with no luminosity showing at the apex from which the liquid thread was being drawn as before.

Some readings taken with positive potentials on the larger of the above points are shown by circles on the lower portion of curve *B*. They are seen to correspond closely with values obtained with the point charged negatively. This fact is additional evidence that the current in this range of potentials was carried solely by droplets for both signs of charge, since gaseous discharge currents of the two kinds not only do not commence at the same potential from a given point but also do not increase at the same rate with rise of potential. The same behavior for both discharges would naturally follow as a result of surface instability whose effects are independent of the sign of the charge used. The broken line *E* is added to Fig. 2 to show the rate of increase of current with voltage for a positively charged metal point of 0.2 millimeter radius placed 1.5 centimeters from the plate.

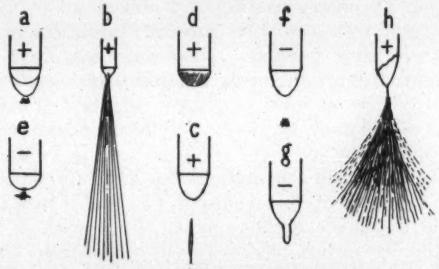
EXPERIMENTS WITH WATER DROPS.

Owing to the greater surface tension of water, drops of this liquid require a considerably higher potential to show instability than do drops of alcohol. Indeed the instability voltage for small drops is here not far from that required to start a glow discharge from a surface of the same curvature, in air at atmospheric pressure. For the smallest of the points used previously the glow discharge actually began with lower fields than were required to initiate instability.[5]

When a galvanometer gives the first indication of a current from a water point, luminous effects are usually seen in the dark, showing the presence of a gaseous discharge. At the same instant, there is a movement of the meniscus which will now be described. As the potential of a drop protruding

from the end of a tube is gradually raised, the pressure inside of the drop must constantly be adjusted if it is desired to maintain the meniscus of hemispherical form. When a certain voltage has been reached the drop suddenly elongates and then the meniscus immediately snaps back to a position where it is flatter than it was beforehand. This is the instant when a momentary current is indicated and when a weak luminous brush may be seen at the elongated position of the meniscus, as shown in Fig. 3*a*. With positive discharges the luminous brush usually had an extended form (Fig. 3*b*), and bridged the whole gap to the opposing plate. Observation of a positively charged point of 0.46 millimeter radius in

FIG. 3.



Discharges from water points under different conditions.

the light from a spark showed at times a fine filament of liquid being ejected from it (Fig. 3*c*), and at other times a number of drops about 0.01 millimeter in diameter. After the meniscus had snapped back, all action, with the same potential, ceased. The stripping of the surface had apparently increased the surface tension and a further rise of potential was required before the above action could be repeated. After a few repetitions the current became permanently intermittent at a fixed voltage and the meniscus appeared blurred in steady light. For positive discharges, this intermittent stage covers at best a small range of voltages after which the current suddenly becomes steady, the meniscus becomes perfectly still, and ejects no liquid whatsoever for

large increases in potential. At the time this change occurs the light accompanying the discharge changes from the brush form described to a thin velvety glow covering a large part of the hemisphere (Fig. 3*d*). The field at the surface of the point is now nearly independent of voltage [2] and is naturally below that requisite for surface instability.

Negative currents remain intermittent and the meniscus is unsteady over a wide range of potentials, usually only becoming quiet for currents above a micro-ampere, when the appearance is that shown in Fig. 3*e*. During the intermittent current stage a small brush of light is visible in the dark some distance below the meniscus, as shown by Fig. 3*f*. In the light of a spark, a short neck of liquid having a diameter about one-fifth that of the tube was seen to project itself intermittently from the meniscus (Fig. 3*g*) almost up to where the brush of light was seen. Its presence doubtless makes the luminous discharge possible. Near the lower limit of these intermittent currents the neck of liquid just described carries a short projection at its tip having a diameter of about one-third that of the main filament. While the negative currents were small and the meniscus could be seen to be undergoing rapid elongations and contractions, no filaments or drops were observed flying from the meniscus nor was a loss of liquid detectable by direct measurement. Thus with a point of 0.46 millimeter radius placed 1 centimeter from the plate, the negative current began at 4,700 volts. With $-$ 4,900 volts the surface was discharging liquid, if at all, at a rate less than 10^{-6} cubic centimeter per second, the smallest amount observable, while at $-$ 5,100 volts the rate of discharge was already 6.5×10^{-5} cubic centimeter per second.

Blowing experiments similar to those described for alcohol points were also done with water points using the same apparatus, shown in Fig. 1, and employing a blast of the same strength as was there used. Since larger potentials are required to start the disruption of water surfaces than are needed for alcohol surfaces of the same curvature, the velocities of identical carriers are greater here and consequently the same blast deflects them less. The results obtained for the effect of the air stream upon the current flowing to plate *B*, Fig. 1, from a point of 0.28 millimeter radius placed 1

centimeter above the receiving plate, will alone be given. The water used was slightly acidulated with hydrochloric acid to increase its conductivity. For positive discharges the meniscus remained agitated over a range of but about 100 volts, and observations here were difficult to make. The following table shows some of the characteristic results.

Water Point.

Radius.	Volts.	Meniscus.	Blast Reduced Current.	Percentage Reduction.
0.28 mm.	+4700	Agitated	From 10 to 8 div.	20
	+4800	Steady	22 to 13	41
	+5000	Steady	167 to 113	32
	−4700	Agitated	200 to 170	15
			Metal Points.	
0.18 mm.	+4200	——	93.5 to 45 div.	52
0.35	+5300	——	182 to 110	40

When a positive potential on the water point was reached where the surface of the meniscus suddenly changed from an agitated to a perfectly steady one, so that drops were no longer ejected, the value of the current decreased by about one-third and the blast was at once more effective in deflecting the paths of the carriers of the current. The last column of the table shows that this behavior is a general one; that when the meniscus is steady and hence not ejecting any drops the blast deflects the carriers more than it does when the meniscus is agitated and emitting drops. These results indicate, then, that where drops were ejected from the meniscus in these experiments they carried a fair portion of the indicated current and their mobilities may have been even larger than those of the gaseous ions comprising the glow discharge. In support of this conclusion, it may be said that owing to the higher surface tension of water the instability potentials for water drops are about 1.7 times larger than those for alcohol drops and, as Table I shows, it is possible for water drops to carry charges that would give them mobilities larger than those possessed by air ions. This is especially likely to be the case because the water drops are apparently larger than the alcohol drops studied, since they can be made individually

visible [10] while all attempts made thus to see the alcohol drops have failed. Since the drops enter the air stream from places of greater field intensity, any persistence of momentum would make their mobilities appear larger than they really are, and this effect would increase with the size of the drops.

It is to be noted in the table above that the effect of the blast on the currents from metal points was even greater than on those from liquid points with steady surfaces. This behavior may possibly be explicable on the basis of previous findings [16] which showed that positive ions have larger mobilities in moist air than they do in dry air.

An unusual form of discharge for water points in air at atmospheric pressure was first observed with a point of 0.13 millimeter radius after the glass tube had become broken off obliquely as shown in Fig. 3*h*; and was later observed with other points similarly treated. With small positive currents a steady, pointed form of meniscus appeared, similar to the one noted for alcohol points. Here too a continuous fine filament of liquid was pulled from the tip end of the drop and broke up into a large number of individually invisible droplets. In a strong, steady light the droplets appeared as a colored fog consisting of an inner more or less conical portion covered by a mantle of a different color, duplicating almost exactly the appearance of the conical form of discharge with alcohol. The two portions doubtless have different sized drops that probably are the two sizes which form when any liquid cylinder breaks up into drops.

The above discharge became self-luminous only after the current had reached a value of 3×10^{-7} ampere, at which time the meniscus became wobbly and larger drops began to fly from it. It is probable, therefore, that here too the smaller currents from this water point were carried solely by charged droplets. The form of discharge described above appears regularly with water points for small currents when the air pressure around the points is increased somewhat above that of the atmosphere.

One of the noteworthy features of the phenomena attending the disruption of drops falling in strong electric fields, exhibited by Macky's [10] photographs and to which he refers,

[16] J. Zeleny, *Phys. Rev.*, **36**, 35 (1930).

is the great difference between the nature of the filaments pulled out from the two ends of the drops. The end of a drop that is charged positively by induction has a very long filament drawn out from it which breaks up into a large number of drops of visible size. The negative end, on the other hand, shows only a short knob-like projection, having an appearance somewhat like that shown in Fig. 3g, and drops in the neighborhood are neither apparent nor mentioned by Macky. In a symmetrical drop (uniform horizontal field) the effects of surface instability should be independent of the sign of the surface charge, and so the difference noted between the actions at the two ends of the drop must in some way be connected with the gaseous discharges which are initiated while the disruption of the drop is in progress. The following explanation is suggested. The electric intensity at the two ends of the drop gradually increases while similar portions of liquid start to be pulled from them and the value of this field becomes sufficient for starting a glow discharge from the negative end before the higher value required for a positive discharge is reached. Once started the discharge stops further elongation of the filament from the negative end of the drop, since the discharge lowers the field at the surface.[5] The positive end of the drop, however, continues to be drawn out to great length before the more spectacular positive brush discharge can begin. Macky mentions the glow seen at the blunt negative ends of drops falling in horizontal fields but makes no mention of such a glow on drops falling in vertical fields, where indeed it may not be distinguishable, even if present, because, owing to the persistence of vision, its elongated retinal image is overlapped by the more extensive positive brush. In horizontal fields the two images appear side by side.

Proteins and Carbohydrates in the Diet.—A modern food fad is based on a presumed incompatability of proteins and carbohydrates in the same meal. MARTIN E. REHFUSS (*Jour. Am. Med. Asso.*, 1934, CIII, 1600–1603) has used hamburger steak as a protein food, and mashed potatoes as a carbohydrate food. Fifty subjects were used; on one morning, each subject received 100 grams of hamburger steak for breakfast; on another morning, each subject received for breakfast 100 grams of hamburger steak plus 100 grams of mashed potatoes. In each experiment, the evacuation time of the stomach was determined by the method usually employed in fractional gastric analysis. The average gastric evacuation time was 3 hours, 51 minutes for the meal of hamburger steak, and 3 hours, 54 minutes for the meal of hamburger steak plus mashed potatoes; the actual difference in average gastric evacuation time was but 3 minutes. These results demonstrated absolutely the inaccuracy of any claim that proteins and carbohydrates are incompatible in the stomach. On still another day, 43 of the subjects received for breakfast a meal consisting of 100 grams of hamburger steak, 100 grams of mashed potatoes, and 40 grams of fat in the form of butter; the average evacuation time of the stomach was 4 hours, 2 minutes. Any type of food, under appropriate conditions, can be handled satisfactorily by the normal human stomach.

J. S. H.

Golden Anniversary of the Association of Official Agricultural Chemists.—This Association has published a booklet of 39 pages to celebrate the fiftieth anniversary of its organization in the year 1884. The brochure contains lists and photographs of the officers of the Association since its first meeting, its constitution, an index to the place of publication of the proceedings of each meeting, a picture of those present at the meeting of 1887, and reminiscences of early members by C. A. Browne.

J. S. H.

A SHORT ACCOUNT OF THE THEORY OF LUBRICATION.[1]

I. INTRODUCTION; VISCOSITY AND FRICTION.

BY

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The laws of lubrication, whether discovered experimentally or deduced theoretically, are particular cases of the general laws of mechanics and thermodynamics. The sum total of information at our disposal regarding these laws or relationships may for brevity be called the science of lubrication.

In the present series of articles we shall be interested primarily in the theoretical formulation of the laws of lubrication. This formulation is based upon the hydrodynamic theory of Reynolds; and so far as can be stated positively at this time, it is in full accord with all available experimental data.

The theory predicts that a condition known as imperfect lubrication will be introduced when the load is too great, the speed or viscosity too low, the rubbing surfaces held parallel, or the quantity of lubricant insufficient. This condition can be almost entirely avoided under modern methods of designing and operating bearings, but is difficult or impossible to escape in the operation of heavy duty gears, and cutting tools. The well known phenomena associated with wear, seizure, and oiliness then take place.

The details of these phenomena are as yet beyond the scope of the theory of lubrication. Recent studies indicate, however, that the condition technically known as *boundary* lubrication, and which might be described as *perfectly* imperfect lubrication, rarely occurs in any practical application unless the rubbing surfaces are absolutely motionless. Apparently then imperfect lubrication occurs only in conjunction with hydrodynamic lubrication, except in the case of station-

[1] From a series of public lectures on "The Science of Lubrication" given at Brown University in 1934, and repeated at Yale University in 1935.

ary surfaces. It also appears probable that some new light may be thrown upon these phenomena when the hydrodynamic theory can be extended to take into account explicitly such factors as the pressure and temperature coefficients of viscosity (Ref. 35).[2]

Both considerations add to the importance of a good working knowledge of the hydrodynamic theory, not simply as a means for understanding the performance of well designed machinery under normal operating conditions, but also, paradoxically, as a step toward the understanding of imperfect lubrication.

The present article deals with fundamental concepts, first reviewing briefly the history of lubrication, and then discussing mathematically the relation of viscosity to frictional resistance. The classical form of the hydrodynamic theory, dimensional theory, and the thermodynamics of lubrication are taken up successively in the three following installments.

HISTORICAL REVIEW.

It appears from existing evidence that all three of the principal classes of lubricants—animal, vegetable, and mineral—were available at an early date. Beef or mutton tallow was apparently used for lubricating the axles of chariot wheels before 1400 B.C., petroleum refining was described by Herodotus (484–424 B.C.), and a list of the vegetable oils had been compiled by Pliny (A.D. 23–79). It has even been inferred from this list that the ancients recognized the need for the heavier or more viscous lubricants under some conditions, and for lighter or more fluid lubricants at other times (Ref. 24).

Lubrication, like every other mechanical action, is governed by Newton's laws of motion upon which the science of mechanics is based. In addition, Sir Isaac Newton (1687) discovered the fundamental law of viscous resistance underlying the theory of lubrication, according to which the shearing stress is proportional to the rate of shear (Refs. 1, 21, 27). The constant of proportionality was later called viscosity.

[2] References to publications will be found at the end of the article, where they have been arranged chronologically by years, and alphabetically by authors within any one year.

Certain liquids such as rubber solutions and oils containing soap, which do not follow this law exactly, are described as non-Newtonian liquids (Ref. 41).

Amontons (1699) and Coulomb (1785) discovered that the coefficient of friction, or ratio of tangential resistance to the normal component of the load, is constant for dry and imperfectly lubricated surfaces over a considerable range of contact area, speed, and load. Morin (1832 +) confirmed the Amontons-Coulomb law for a wider variety of materials, and conducted systematic experiments on journal bearings. He found the coefficient was reduced to about one-half when the lubricant was continuously renewed.

Hirn (1854) discovered the effect of running-in, and concluded that the friction of lubricated surfaces might be taken as roughly proportional to the square roots of the area, load, and speed.

Thurston (1873 +) was a pioneer in the testing of lubricants and drew attention to the importance of reducing friction losses in machinery. He discovered the existence of a minimum point when the coefficient of friction is plotted against speed or temperature. To Thurston is due the widely quoted rule that the safe load per unit area is inversely proportional to the speed. Although not applicable to modern high speed bearings, it illustrates the need for some definite relation connecting load capacity with speed as a starting point for bearing design.

Petroff was awarded a prize by the Russian Academy of Sciences for his investigation published in 1883 (Ref. 3), in which he demonstrated the utility of petroleum oils by showing that it depended merely on selecting a suitable viscosity for each application. He also deduced at this time the first mathematical formula for the friction of a journal bearing, treating the case of a full bearing operating with a uniform film thickness, discussed below.

The modern understanding of lubrication rests upon the experiments of Beauchamp Tower (1883 +) and their interpretation by Osborne Reynolds. Tower's experiments were conducted for a Committee of the Institution of Mechanical Engineers. The journal bearings tested were partial bearings of 157 degrees arc, similar to those used in railway service;

the journal 4 inches in diameter; the bearings 6 inches long. Oil was supplied first by a syphon lubricator, then by a pad, and finally by means of a bath. The friction with bath lubrication was found surprisingly low.

All the information which the Committee sought for was obtained. But now observe carefully what happened. In anticipation of installing a lubricator, a half-inch hole had been drilled in the center of the brass. An outflow of oil then occurred when running the machine. To prevent it, a wooden plug was driven into the hole; and on starting up again, the plug was slowly forced out. This precise moment appears to have been the turning point in the history of lubrication. A pressure gage was attached and indicated a true fluid pressure in the film, at the center of the bearing, sometimes as great as twice the mean pressure computed by dividing the total load by the projected area of the bearing.

Reynolds perceived at once, from Tower's experiments, that lubrication was a hydrodynamic action. Petroff had recognized the connection between viscosity and friction, but it remained for Reynolds to explain the load carrying power of the oil film, and to extend the friction problem to the case of an eccentric bearing. His classical paper of 1886 (Ref. 4) contains three principal contributions, (1) a general picture of the physics of lubrication, capable of a more complete formulation than has yet been undertaken; (2) a differential equation for the pressure distribution in the film, capable of many future applications; and (3) application to Tower's experiments. The most significant result of Reynolds' theory is the principle of the converging film. The lubricant adheres to both the moving and stationary surfaces; and by virtue of its viscosity, develops a positive fluid pressure in the converging portions of the film. This pressure supports the load and prevents metallic contact. No such pressure can be developed between strictly parallel surfaces.

While Reynolds' paper of 1886 is notable for its involved character, it is not so commonly known that he was the author of a shorter and more readable article in the Encyclopedia Brittannica (Ref. 9).

Albert Kingsbury, working in the laboratory of Professor Thurston at Cornell, 1888–1889, found that certain differences

in friction, attributed to the composition of the bearing metals, disappeared when sufficient care was taken in fitting the bushings to the journal. This is in accord with the theory of Reynolds, and demonstrates the importance of accurate mechanical workmanship in lubrication investigations. Kingsbury discovered a few years later, by microscope observations, how the lubricant is drawn into the space between the bottom of the chip and the top surface of a cutting tool. A machine for testing the friction of screws was described by Kingsbury at the 1895 Annual Meeting of the American Society of Mechanical Engineers. Mineral oil, lard oil, and mineral oil containing graphite were compared on both ferrous and non-ferrous metals under loads up to 14,000 pounds per square inch.

Returning to the study of perfect, or fluid-film lubrication, Kingsbury conducted his classical experiments on the air-lubricated journal bearing. A report was published in 1897 by the American Society of Naval Engineers (Ref. 8). Careful measurements had been made, at varying speeds, of the pressure distribution in the film, the position of the journal in the bearing, and the friction torque on the journal. Confirmatory results were obtained using hydrogen as the lubricating fluid. These observations were in close agreement with Reynolds' theory. It was evident that the essential property of a lubricant is something possessed in common by liquids and gases, namely, viscosity; and that an important requirement for perfect lubrication is the converging film.

Kingsbury now applied the principle of the converging film to the design of thrust bearings. This was done by dividing the bearing surface into segments, each pivoted so that it was free to adjust itself to the proper angle of inclination with the opposite rubbing surface, or runner.[3] The first Kingsbury thrust bearings were constructed at the New Hampshire State College. They were tested in comparison with ordinary thrust bearings on the machine already mentioned, which had been used for determining the friction of screws. These tests were reported in theses by Baker and Putney in 1899. Further tests were conducted at the Worcester Polytechnic Institute during the following year,

[3] Demonstrated in the lecture room by means of an air-lubricated model.

1899–1900; and the Kingsbury machine on which all these tests were made may still be seen by visitors at the Institute, together with the original air-lubricated journal bearing.

Pivoted shoe bearings were independently developed by the Australian engineer, A. G. M. Michell, as a result of his mathematical studies published in 1905, to be reviewed in our next installment. Both inventors attributed their inspiration to the theory of Osborne Reynolds. Subsequent tests by Howarth and others have fully confirmed the superiority of the pivoted shoe thrust bearing over other types previously used, particularly as applied to the larger hydroelectric and marine installations.

A more detailed account of the history of lubrication will be found in a series of articles now being published by the American Society of Naval Engineers (Ref. 36).

NEWTON'S LAW AND THE DEFINITION OF VISCOSITY.

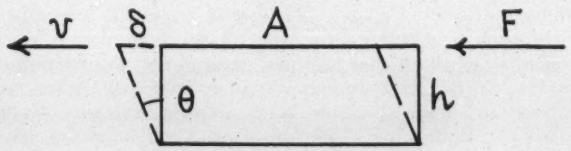
Newton's law states that at any point in a fluid the shearing stress is directly proportional to the rate of shear; or if S denotes the shearing *stress* (tangential force per unit area) while R denotes the *rate* of shear,

$$S = \text{const. } R. \qquad (1)$$

Shearing deformations are familiar in problems of elasticity, for example in the twisting of a rod or wire. The analogy is a close one, the difference being that in the lubrication problem we shall be interested in the time rate or velocity of deformation, rather than in the amount of the deformation.

Figure 1 represents any small volume element of a solid or fluid undergoing a shearing deformation without acceleration. The full lines indicate the original shape of a cross

FIG. 1.



Shearing deformation of a small volume element.

section of this element. The broken lines indicate the deformed shape of the same identical material after a short interval of time. The tangential force F is acting upon an area A; when equilibrium has been reached, this force is balanced by others not shown. Let h be the height of the element, and v the velocity of the upper surface relative to the lower surface. Also let δ represent the displacement of the upper surface, or distance that a given point has moved relative to the lower surface. Assume for the present that the element as a whole is not rotating. The tangent of the angle θ, which measures the total amount of the shear, is equal to δ/h. In this case the rate of shear, R, is equal to the velocity gradient, v/h.

For the elastic body, Hooke's law states that when equilibrium has been reached, the shearing stress F/A is equal to a constant times the amount of shear, δ/h. For the fluid, Newton's law states that F/A is equal to a constant times the rate of shear, v/h. The constant of Hooke's law is known as the shear modulus, or rigidity. The constant of Newton's law is known as the coefficient of viscosity, or in present day language, the viscosity.

Denoting the viscosity of the fluid by μ, Newton's law may be written

$$S = \mu R; \tag{2}$$

and we have for the definition of viscosity simply the ratio of shearing stress to rate of shear, S/R. When the velocity distribution is linear, $R = v/h$ and (2) reduces to

$$\frac{F}{A} = \mu\left(\frac{v}{h}\right). \tag{3}$$

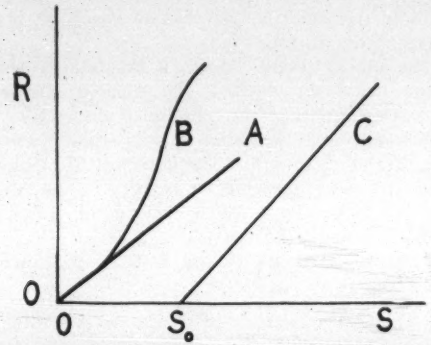
When the distribution is not linear, the gradient may be expressed by the corresponding differential notation.

In problems where the relative velocity of two surfaces is not entirely due to the internal movement, or deformation, of the material but is partly accounted for by rotation, it is necessary to subtract the angular velocity ω from the velocity gradient to obtain the rate of shear. The reason becomes obvious on contemplating the rotation of a rigid body. Here the velocity gradient is finite and equal to the angular velocity, yet there is no actual deformation. The correction may be

neglected when the numerical magnitude of ω is small compared to the velocity gradient. This will be true for journal bearings, but not for such a problem as the rotation viscometer, where the radial clearance may be as large as half the radius of the inner cylinder.

Whenever the R, S or rate of shear vs. shearing stress diagram passes through the origin the material is classed as a liquid, even though it may not follow Newton's law (graph B, Fig. 2). When the diagram shows an intercept on the stress

FIG. 2.



Rate of shear, R, plotted against shearing stress, S (A, simple viscous liquid; B, non-Newtonian liquid; C, plastic solid of the Bingham type).

axis, the material is classed as a plastic solid. Flow begins only after the yield shear stress, S_0, has been reached. If the graph of the plastic solid approximates a straight line, it is known as a Bingham solid, from the work of Professor E. C. Bingham (Ref. 15). The study of plastic and other non-Newtonian materials promises to be of importance in future lubrication investigations (Refs. 25, 30), particularly at low temperatures, and has led to the science of *rheology* (Refs. 32, 41).

Kingsbury's experiment with the rotating tapered plug, Ref. 12(a), indicated no slip and no significant deviation from Newton's law as applied to ordinary lubricating oils up to rates of shear as high as 260,000 radians per second and

down to film thicknesses of the order of 1/40,000 inch. For bearing clearances of 0.002 inch (difference in radii 0.001 inch) the above rate of shear corresponds to a surface speed of about 22 feet per second, or to 5,000 revolutions per minute on a diameter of one inch. Bulkley's experiments with very fine capillary tubes of glass and of metal (Ref. 28), using both fatty and mineral oils, showed that if the adsorbed film on the solid surface is of a plastic nature, as had been suggested, it cannot exceed about one-millionth of an inch in thickness. This limit corresponds to a very heavy load, and indicates that Newton's law may safely be relied upon for the ordinary purposes of bearing design.

APPLICATION TO PETROFF'S EQUATION AND POISEUILLE'S LAW.

Consider first the problem of a concentric, full journal bearing; that is, one which is lightly enough loaded and running at a high enough speed that the journal is well centered in the bearing, and the film of a practically uniform thickness all around. Imagine the volume element in Fig. 1 to be elongated and wrapped around the journal so as to constitute the entire film. Let it be required to compute the equivalent tangential force F necessary for maintaining a constant surface speed v. We may replace the area A in Eq. (3) by πDL, where D is the diameter of the journal and L the length of the bearing (Fig. 3). Similarly v may be written πDN, where N is the speed in revolutions per unit time; and the film thickness h may be written $C/2$, where C is the clearance or difference between bearing diameter and journal diameter. Eq. (3) then reduces to

$$F = 2\pi^2 \left(\frac{D}{C}\right)\left(\frac{L}{D}\right)\mu N D^2; \qquad (4)$$

and the torque, or moment of friction, obtained on multiplying by the radius, will be

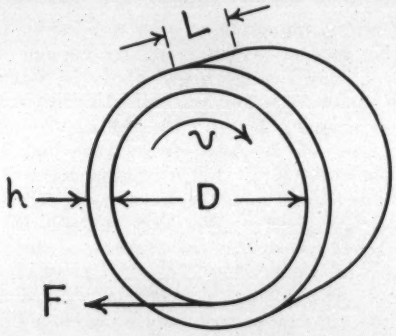
$$T = \pi^2 \left(\frac{D}{C}\right)\left(\frac{L}{D}\right)\mu N D^3. \qquad (5)$$

While these results might be simplified by cancelling D's, it is found more convenient in practice to express such relations in terms of the length-diameter and clearance-diameter ratios.

Thus it appears that for any given bearing, the friction torque is proportional to the viscosity of the lubricant and the speed. For bearings of the same diameter with different shape factors, the torque is directly proportional to the length and inversely as the clearance. For bearings of different sizes but geometrically similar, the torque is proportional to the cube of the absolute size.

Petroff treated the problem as a special case of Margules' solution for the rotation viscometer, which had already been published. Both Margules and Petroff included certain terms in their formulas to allow for the effect of slip between the

FIG. 3.



Journal surrounded by a film of uniform thickness.

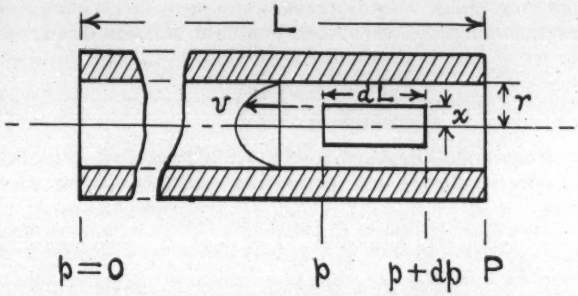
lubricant and the metal. These terms are now believed superfluous and when they are omitted, Petroff's formula reduces to Eq. (5).

As a second example of the application of Newton's law, we may consider the derivation of Poiseuille's law; or, as it is often called, the Hagen-Poiseuille law, for although discovered by Poiseuille in 1840, it had been derived by Hagen in 1839. A thorough understanding of this problem will also be useful in connection with the technique of viscosity measurement.

A cross section of the capillary is shown in Fig. 4. It will

be assumed long enough that end-effects and the kinetic energy correction are negligible. Let L be the total length and r the radius of the tube. Consider first a cylindrical volume element of the fluid, of length dL and radius x. Suppose the flow is from right to left along the tube and let p denote the hydrostatic pressure at any point, relative to the pressure at the outlet. Then the pressure on the downstream face of the volume element may be denoted by p and the pressure on the upstream face by $p + dp$, while P designates the pressure at the inlet end of the tube.

FIG. 4.



Pressure drop and velocity distribution in a capillary tube.

The resultant force tending to push the volume element downstream is the product of the pressure difference dp into the area πx^2. This force is resisted by the shearing stresses due to viscosity, assuming the fluid adheres to the walls of the tube. Let v denote the velocity at radius x; then the velocity gradient with respect to increasing values of x is negative and equal to dv/dx, where dv is the difference in velocities at the radial distances x and $x + dx$ from the axis of the tube. Let S denote the shearing stress at radius x, i.e. the tangential force per unit area exerted upon the cylindrical surface of the volume element by the fluid remaining between it and the wall of the tube. The total shearing resistance, a force acting upstream toward the right, is the product of S into the area $2\pi x \cdot dL$. Under steady flow

conditions (no acceleration) this resistance must just equal the downstream force on the element due to the pressure drop, i.e.

$$S \cdot 2\pi x \cdot dL = \pi x^2 \cdot dp \tag{6}$$

from which

$$S = \frac{x}{2}\left(\frac{dp}{dL}\right). \tag{7}$$

Thus the shearing stress at any radius is equal to one-half the product of the radius into the pressure gradient, a useful general relation independent of the nature of the fluid. In particular the shearing stress at the wall of the tube is equal to $r/2$ multiplied by the pressure gradient, or pressure drop per unit length. When conditions are uniform throughout the whole length of the tube (7) may be written

$$S = \frac{x}{2}\left(\frac{P}{L}\right). \tag{8}$$

If the fluid is one that follows Newton's law, $S = -\mu(dv/dx)$. Substituting in (8) and integrating with $v = 0$ when $x = r$ gives

$$v = \frac{1}{4\mu}\left(\frac{P}{L}\right)(r^2 - x^2). \tag{9}$$

This takes the form of a parabola as indicated in Fig. 4. Now our object is to obtain some relation connecting the efflux, Q, in volume units per unit time with the pressure drop and viscosity. This can be done by integrating the velocity over the cross section, since the product of the fluid velocity into an element of area must equal the volume per unit time flowing through the element. The velocity may be taken as uniform throughout any ring-shaped element of area $2\pi x \cdot dx$. Multiplying both sides of (9) by this factor and integrating gives

$$Q = \frac{\pi}{8}\left(\frac{P}{L}\right)\frac{r^4}{\mu}, \tag{10}$$

the usual form of Poiseuille's law. A more general equation has been obtained for high pressure experiments, where the viscosity varies along the tube (Refs. 11, 31).

MEASUREMENT OF VISCOSITY.

The simplest procedure for measuring the viscosity of a liquid with an accuracy of 2 per cent. or better consists in setting up a glass or metal capillary, which can be totally immersed in a temperature control bath, and having a ratio of length to internal diameter not less than 50. The inlet pressure may be measured on any suitable gauge and should be held reasonably constant during the period of efflux. The effective radius may be determined by calibration with some liquid of known viscosity, as, for example, water, sugar solutions, or standard viscosity samples from the National Bureau of Standards. Let the constant factor $(\pi/8)(r^4/L)$ of Eq. (10) be represented by C; then in practice the viscosity of the test liquid is to be computed from observations of P and Q by means of the working formula

$$\mu = \frac{CP}{Q}, \tag{11}$$

corrected if necessary for kinetic energy, temperature inequalities, and end effects (Refs. 15, 27).

Almost any mechanical phenomenon sufficiently influenced by viscosity may be adopted for viscosity measurement. An intriguing variety of methods will be found in the literature of viscometry, including the ball and slanted tube of Flowers,[4] rotation viscometers, the falling sphere, rising bubble of air, cup and ball type of Michell, and the balance type of Duffing (Refs. 10, 11, 27, 42).

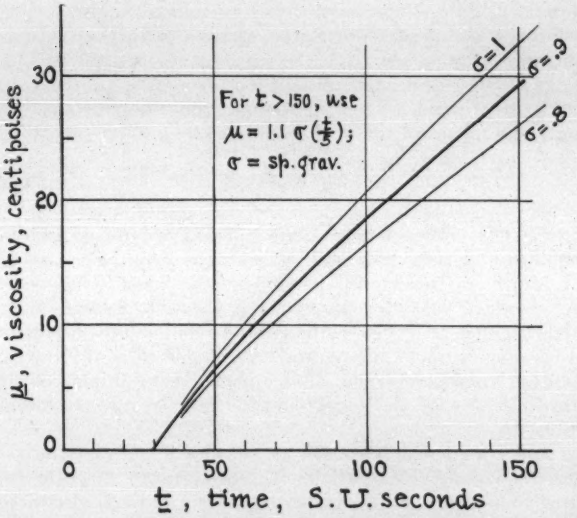
The commercial viscometers so widely used in the petroleum industry are fitted with outlet tubes that are too short to be described as capillaries. For very high viscosities the efflux times are inconveniently long; for low viscosities they are complicated by kinetic energy and turbulent motion. In either case the flow takes place under a falling head; and the effective temperature of the sample is uncertain. The standardization of such instruments (Refs. 13, 39) has brought about a reasonable degree of uniformity, but at the

[4] The relative viscosities of familiar liquids such as kerosene, winter and summer automobile oils, and castor oil may be shown in the lecture room with glass tubes of ½-inch inside diameter, each containing a ⅜-inch steel ball and corked at both ends after filling.

risk of perpetuating the complications (Refs. 34. 40). The situation was reviewed at the World Petroleum Congress, London, 1933, where it was voted to adopt c.g.s. units (Ref. 42).

Figure 5 shows the approximate relation connecting Saybolt Universal readings, t, with viscosity, μ, for specific gravities ranging from $\sigma = 0.8$ to $\sigma = 1.0$. It will be noted

FIG. 5.



Conversion from Saybolt seconds to viscosity in centipoises.

that the reading changes less than 10 per cent. (i.e. from 32 to 35 seconds) for 100 per cent. increase in viscosity in the range from 1 to 2 centipoises. Thus the commercial instruments are insensitive to differences in viscosity in the low viscosity range; and at best give only the ratio of viscosity to density (kinematic viscosity), requiring a knowledge of the specific gravity before the viscosity can be computed. For the higher viscosities, a convenient rule to remember is that

the equivalent number of centipoises for a liquid of specific gravity 0.9 is approximately equal to one-fifth the number of Saybolt seconds.

The centipoise is one-hundredth of the c.g.s. unit, or poise, named after Poiseuille. The poise is the viscosity of a fluid requiring a shearing stress of one dyne per square centimeter to maintain a rate of shear equal to one centimeter per second per centimeter thickness. More simply stated, this rate of shear is equal to one radian per second, or one reciprocal second, and so the poise is identical with one dyne-second per square centimeter. The common engineering unit for lubrication computations in European countries is the kilogram-second per square meter. In English speaking countries, when pressures have been given in pounds per square inch the pound-second per square inch is a logical unit. This was the unit employed by Reynolds.

It is not difficult to convert viscosities from one system of units to another with the aid of Eq. (3) and Fig. 1; in this way Table 1 has been compiled for use to three significant figures.

TABLE 1.

Viscosity Units.

(*a*) *Conversion from poises:*

One poise or dyne sec./cm.^{2} =
1.02×10^{-2} kg. sec./m.^{2}
2.09×10^{-3} lb. sec./ft.^{2}
1.45×10^{-5} lb. sec./in.^{2}
2.42×10^{-7} lb. min./in.^{2}

(*b*) *Conversion into poises:*

One kg. sec./m.^{2}	=	98	poises
" lb. sec./ft.^{2}	=	479	"
" lb. sec./in.^{2}	=	69,000	"
" lb. min./in.^{2}	=	4,140,000	"

VISCOSITY-TEMPERATURE RELATIONS.

The viscosity of a gas increases slightly with rising temperature, or about in proportion to the four-fifths power of the absolute temperature (Ref. 18), while that of a liquid decreases rapidly (Refs. 16, 29). Reynolds expressed the results of his observations on olive oil (Ref. 4) by

$$\mu = ae^{-bt}, \qquad (12)$$

where t is the temperature and a and b are constants.

Slotte (Ref. 5) introduced a three-constant formula which may be written

$$\mu = \frac{a}{(t - c)^b} \tag{13}$$

and is applicable over a wider range. Reynolds' formula is one of the most convenient for analytical use. For numerical work Slotte's formula may be expressed in a two-constant form by assigning a fixed value to one of the empirical coefficients. This has usually been done by putting $c = -18°$ C. $= 0°$ F., in which case (13) reduces to $\mu = a/t^b$, or

$$\log \mu = \log a - b \log t, \tag{14}$$

provided the Fahrenheit scale is used.

The numerous formulas proposed up to 1897 were reviewed by Duff (Ref. 7) who discovered that all were integrals of the same differential equation,

$$\frac{1}{\mu}\left(\frac{d\mu}{dt}\right) = \frac{1}{a + bt + ct^2}. \tag{15}$$

The expression $(1/\mu)(d\mu/dt)$ has a simple physical interpretation. It is the temperature coefficient of viscosity, or fractional change in viscosity per degree rise of temperature at any temperature t. Professor Duff's observations may therefore be expressed by the statement that the temperature coefficient is inversely proportional to a simple quadratic function of the temperature. Putting $c = 0$ we obtain Slotte's formula, and with both b and c equal to zero, integration gives Reynolds' formula.

Many years after the publication of Duff's investigation a new formula was constructed by Vogel (Ref. 17) which has recently come into very wide use. This may be written

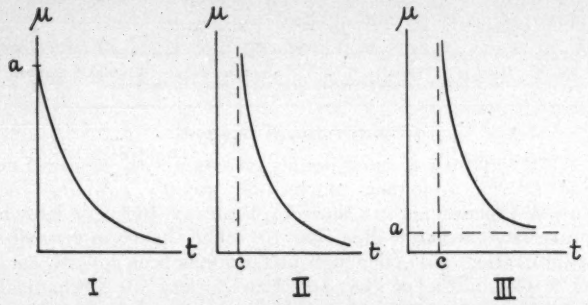
$$\log \mu = \log a + \frac{b}{t - c} \tag{16}$$

and is also an integral of Duff's equation.

The geometrical interpretation of the constants a and c in Eqs. (12), (13), and (16) is suggested by Fig. 6. Note that a of Slotte's formula is equal to the viscosity one degree

above the critical temperature c; and that b in all these formulas may be determined from the slope of the straight line obtained when the logarithm of the viscosity is plotted against the appropriate temperature variable. For Reynolds' formula this variable is the temperature itself. For Slotte's it is the logarithm of the temperature difference, measured above the critical temperature c; and for Vogel's it is the reciprocal of the temperature difference. From a physical viewpoint c may be interpreted as the apparent solidifying temperature, keeping in mind that these formulas are intended merely as approximations.

FIG. 6.



Graphical representation of viscosity-temperature formulas (I, Reynolds'; II, Slotte's; III, Vogel's).

Table 2 shows the order of magnitude of the temperature effect for a number of actual fluids, the relative viscosity being taken as unity at a standard temperature of 25° C. (77° F.). Mineral oils known as "high viscosity index" oils are now available which are less affected by temperature than the paraffin base oil of Table 2.[5]

[5] Differences in the viscosity-temperature characteristics of two or more mineral oils having the same viscosity at room temperature may be demonstrated with the ball and tube. The tubes are packed vertically in a large bottle of ice or snow an hour or more in advance. Roll-times are observed immediately on withdrawing from the ice, to obtain the maximum contrast; and again at the close of the lecture hour, when it will be seen that the viscosities have practically equalized.

TABLE 2.
Relative Viscosity at Different Temperatures.

Temperature.		Air.[a]	Water.[b]	Lard Oil.[c]	Mineral Oils.[d]	
° C.	° F.				*A.*	*B.*
0	32	0.93	2.00	3.5+	5.3+	6.4
20	68	0.99	1.13	1.25	1.32	1.35
25	77	1.00	1.00	1.00	1.00	1.00
30	86	1.01	.90	.82	.76	.75
50	122	1.07	.61	.42	.31	.28
100	212	1.20	.32	.12	.075	.062
Ratio $\left(\frac{0° \text{ C.}}{100° \text{ C.}}\right)$		0.78	6.2	30	71	103

[a] Ref. 18. [b] Ref. 15. [c] Refs. 22, 23, 29. [d] *A*, paraffin base (100 V.I.); *B*, naphthene base (0 V.I.); same viscosity as lard oil at 25° C., about 66 centipoises.

VISCOSITY-PRESSURE RELATIONS.

The viscosity of most liquids increases with pressure; at first slowly, and then much more rapidly. Among the earliest experiments are those by Professor Barus of Brown University on marine glue (Ref. 6). The change in viscosity of lubricating oils under high pressure has been investigated by a Committee of the American Society of Mechanical Engineers, and discussed in a series of papers beginning in 1916 (Refs. 11, 12, 22, 23, 31). Further experiments have been conducted by Hyde at the National Physical Laboratory, by Kiesskalt at Karlsruhe, and by Suge at Tokyo (Refs. 14, 20, 33).

Professor Barus found that his results were in accord with formulas of the type

$$\mu = \mu_0 e^{-at} \cdot e^{bp} = \mu_1 e^{bp} \qquad (17)$$

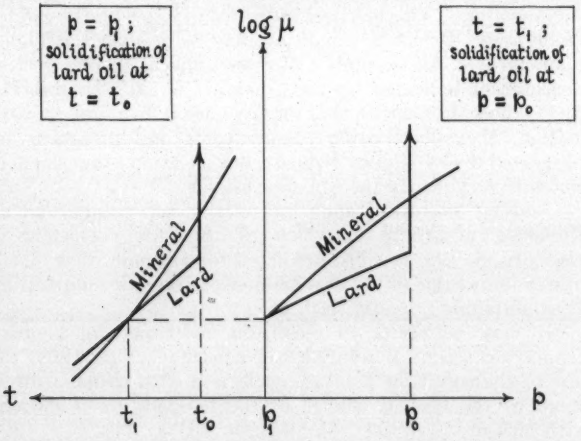
over a moderate range, although Eq. (17) gave too great a change in viscosity with pressure at the higher pressures. In this equation μ_1 is the viscosity at the temperature t and atmospheric pressure ($p = 0$), while μ denotes the viscosity at any temperature t and pressure p; and μ_0, a and b are constants. Recent formulas proposed by Kiesskalt, Suge,

and others (Refs. 20, 31, 33(b), 37, 38) are very nearly equivalent to Eq. (17) which may be taken as a convenient representation of the viscosity-temperature-pressure relation over a limited range of the variables. For extreme pressures such as may occur in the lubrication of gear teeth and cutting tools, and between the impinging rough spots on bearing surfaces not separated by a thick film, graphical representation is more accurate. Differentiating (17) gives for the pressure coefficient of viscosity, to a first approximation,

$$\frac{1}{\mu_1}\left(\frac{d\mu}{dp}\right) = b. \tag{18}$$

The general character of the change in viscosity with pressure and temperature is indicated by the logarithmic diagrams in Fig. 7 and the numerical data in Table 3. As

FIG. 7.



General nature of the viscosity-temperature-pressure relation for lard oil and a naphthene base mineral oil.

discovered by Hyde, the effect of pressure is more pronounced on mineral than on fatty oils. It will be recalled that the same is true of the temperature effect.

TABLE 3.
Relative Viscosity at Different Pressures.

PRESSURE.		WATER.[a]		LARD OIL.[b]		MINERAL OIL.[c]	
Kg. per sq. cm.	Lb. per sq. in.	0° C. (32° F.)	75° C. (167° F.)	22° C. (72° F.)	100° C. (212° F.)	25° C. (77° F.)	100° C. (212° F.)
1	14.2	1.00	1.00	1.0	1.0	1.0	1.0
1000	14,200	.92	1.08	4.2	2.8	23	4.3
2000	28,400	.96	1.16	Sol.[d]	5.6	280	15
4000	56,900	1.11	1.36	"	17.4	—	112

[a] Ref. 19. [b] Ref. 22. [c] Ref. 22, naphthene base (extrapolated). [d] Solidification begins at 1500 kg. per sq. cm. (about 21,000 lb. per sq. in.).

When the temperature is sufficiently reduced at atmospheric pressure, certain oils, notably lard oil and mineral oils containing paraffin wax, approach a condition of apparent solidification. This has been indicated in Fig. 7 by the sudden break at t_0. A similar condition may be produced at higher temperatures, for example t_1, by the application of sufficient pressure, as indicated by the break at p_0. It was observed by H. Shore, Ref. 23(b), that for any one oil, to a first approximation, the solidification temperatures and pressures are connected by a simple straight line relation, the slope of which is very nearly the same for all oils.

Another interesting empirical relation was pointed out by Kiesskalt, according to which the pressure coefficient of viscosity may be roughly predicted for any one class of oils from a knowledge of the change in viscosity with temperature at atmospheric pressure (Ref. 26).

It may be useful to recall the mathematical identity connecting second derivatives, in consequence of which the rate of change of the pressure coefficient with temperature is equal to the rate of change of the temperature coefficient with pressure.

POWER LOSSES AND THE COEFFICIENT OF FRICTION.

The power consumed by friction and dissipated into heat in a bearing is equal to the work done per unit time against frictional resistance. Thus the power loss in a journal

bearing is given by

$$H = \omega T = 2\pi NT, \tag{19}$$

where T is the friction torque on the moving part (usually the journal), ω the angular velocity, and N the number of revolutions per unit time. It is important to remember that (1) in general the friction torques on the journal and bearing are not equal unless the journal is concentric with the bearing; and (2) the applied torque is equal to the friction torque only when there is no acceleration. If in Eq. (19) T is expressed in pound-feet and N in revolutions per second, H will be in foot-pounds per second; and the friction horsepower is obtained upon dividing by 550.

In problems of translatory motion the ratio of the friction to the load perpendicular to the surface is known as the coefficient of friction. In rotation problems the coefficient is defined as the ratio of the equivalent friction, F, to the total load, W, or $f = F/W$. This equivalent friction is defined as the ratio of the friction torque to the radius, or $F = 2(T/D)$ where D is the diameter. Combining the two equations, we have as a matter of definition

$$f = 2\left(\frac{T}{DW}\right). \tag{20}$$

As before, a distinction must be made between the coefficient of bearing friction and the coefficient of journal friction.

Eliminating T between (19) and (20) gives for the power loss, H, in terms of the friction coefficient, f,

$$H = fW \cdot \pi DN = fW \cdot U, \tag{21}$$

where U is the surface velocity.[6] Equations (19) to (21) are perfectly general and do not rest on any particular assumption regarding the state of lubrication of the bearing. They are in fact applicable to thrust bearings as well as to journal bearings when the effective diameter D is appropriately defined.

In the particular case of a journal bearing lightly enough loaded to satisfy Petroff's equation we may substitute from

[6] The notation for surface velocity has been changed at this point from v to U for consistency with the literature of the hydrodynamic theory.

(5) into (19) to obtain a relation connecting power loss with viscosity,

$$H = 2\pi^3 \left(\frac{D}{C}\right)\left(\frac{L}{D}\right)\mu N^2 D^3. \tag{22}$$

It is, however, of special interest in lubrication investigations to compare the various expressions found for the coefficient of friction. Substituting from (5) into (20) and letting P denote the load per unit of projected area, W/LD, gives for the coefficient

$$f = 2\pi^2 \left(\frac{D}{C}\right)\frac{\mu N}{P}, \tag{23}$$

which may be considered an alternative form of Petroff's equation.

FRICTION IN FILMS OF NON-UNIFORM THICKNESS.

Lamb in his treatise on hydrodynamcs (Ref. 2) gives a general theorem for the power dissipated in a viscous fluid in terms of the space derivatives of the velocity components u, v, and w. As applied to lubrication, assuming the lubricant incompressible, Lamb's theorem may be written, to a close approximation,

$$H = \int\int\int \mu \left(\frac{du}{dy}\right)^2 dxdydz. \tag{24}$$

In Eq. (24) and subsequent formulas the coordinate x will be taken in the direction of motion, y normal to the bearing surface, and z at right angles to x and y, while u is the fluid velocity in the x-direction. From (24) the power dissipated per unit volume of lubricant is equal to the product of the viscosity into the square of the velocity gradient. This relation has been found useful in problems of non-uniform viscosity and non-uniform film thickness. The coefficient of friction may then be computed with the aid of the relation

$$f = \frac{H}{\pi DN \cdot W} = \frac{H}{UW} \tag{25}$$

obtained from (21). As a check it will be noted that (24) reduces to (22) when the viscosity is assumed uniform throughout the clearance volume $\pi DLC/2$, and the velocity

gradient is taken equal to the surface speed πDN divided by the film thickness $C/2$.

Reynolds expressed the frictional resistance per unit area, or shearing stress at any point of the moving surface, in terms of the pressure gradient in the direction of motion. His equation may be written

$$S = \frac{\mu U}{h} + \frac{h}{2}\left(\frac{dp}{dx}\right), \tag{26}$$

where U is the relative velocity of the bearing surfaces in the x-direction; h the variable film thickness; and p the hydrostatic pressure at any point x. When applied to a journal bearing, U may be replaced by πDN. The friction torque is then computed by multiplying the right hand side of (26) by the radius of the bearing and by an element of area, and integrating over the moving surface. When the film is of uniform thickness there is no pressure gradient, $h = C/2$, and the above integration leads directly to Eq. (5). In the general case of non-uniform thickness, however, a knowledge of the pressure distribution is presupposed. This will be discussed in the following installment. The proof of (26) is instructive as an application of Newton's law to a problem where the velocity gradient is not constant over the cross section. The reasoning involved is similar to that used in the derivation of Poiseuille's law.

NUMERICAL EXAMPLE.

As a concrete example, let it be required to compute the friction torque, power loss, and coefficient of friction in the journal bearings of a grinding machine, the following data being given: Length of each bearing, 6 inches; diameter, 3 inches; clearance, one part per thousand; speed, 1200 revolutions per minute; total load on two bearings, 1440 pounds; film temperature, estimated 100° F.; lubricated with a light oil of specific gravity 0.92 commercially rated as 150 seconds Saybolt Universal at the above temperature. From Fig. 5, the viscosity is approximately 30 centipoises; hence from Table 1, $\mu = .30 \times 1.45 \times 10^{-5} = 4.35 \times 10^{-6}$ pound seconds per square inch. Assuming the film to be of a practically uniform thickness, it remains to substitute the appropriate values in Eqs. (5), (19), and (20).

For use in Eq. (5) we have $D/C = 1000$, $L/D = 2$, and $N = 1200/60 = 20$ revolutions per second, besides the values already stated for the viscosity, μ, and diameter, D. Substituting and multiplying out it is found that the torque, T, is equal to 46.4 pound inches or 3.85 pound feet for each bearing. Substituting this value for T in Eq. (19), together with the value already stated for N in revolutions per second, gives for the power loss $H = 485$ foot pounds per second in each bearing. This amounts to about 1¾ horsepower for the whole machine.

No use has been made of the load in computing either friction torque or power loss. The frictional resistance offered by an oil film is independent of the load, except so far as the effective film thickness or viscosity may be altered by the load. In this problem the load is comparatively light, the nominal bearing pressure, P, being 770/18 or 40 pounds per square inch; while the speed is reasonably high, hence it has been solved on the assumption of a uniform thickness. On the other hand, the coefficient of friction is by definition equal to the friction divided by the load and so, in any case where the friction itself is independent of the load, the coefficient must vary inversely as the load. Substituting $T = 46.4$ pound inches, $D = 3$ inches, and $W = 720$ pounds in Eq. (20) gives $f = 0.043$. As a check, the same result may be obtained from either (23) or (25); or the problem may be worked through from the start in a different system of units.

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THE DYNAMICS OF MOLECULAR CRYSTAL LATTICES. III. MODELS OF VIBRATING CRYSTALS.

BY

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INTRODUCTION.

In the study of vibrating molecules the mechanical models of Kettering, Shutts and Andrews [1] have been useful in obtaining an idea of the nature of the vibrations, especially in cases where the system of forces and masses involved is too complex for the usual analytical treatment. Since the study of molecular crystal lattices involves much the same type of problem as is found with individual molecules, we thought it would be interesting to construct vibrating models of some lattices. We wanted particularly to have an aid in visualizing the physical principles involved in the mathematics of lattices and a means of observing the character of the modes of vibration, especially the one associated with the fastest frequency of the lattice. We also wanted to see whether the rotational oscillations of neighboring molecules in the lattice would couple in a manner resembling that of the translational oscillations, and whether one could find a function to express these rotational couplings similar to the Debye function for translational coupling. Finally, there appeared to be considerable interest in observing the effect of increasing the weight of a single atom or molecule in the lattice, the effect one would obtain from the presence of an isotope.

MODEL OF A ONE DIMENSIONAL LATTICE.

In order to get an idea of the problems involved in making models of crystal lattices, the first attempt was directed toward the construction of what might be called a "one-dimensional lattice." The results are included here chiefly

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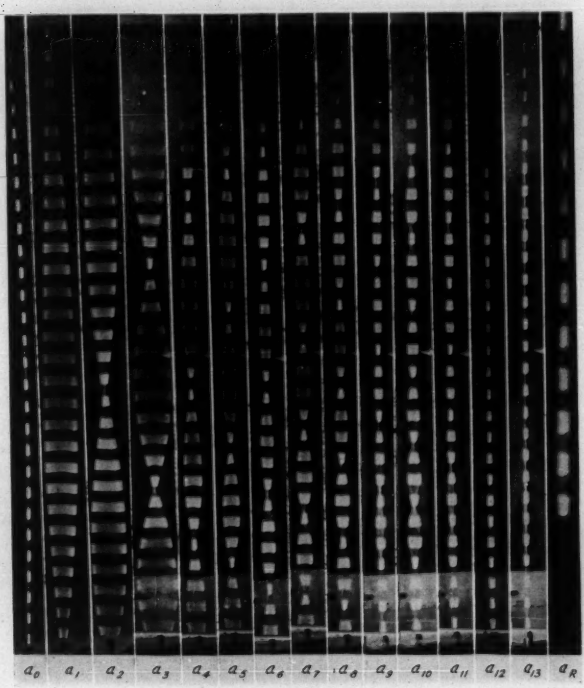
[1] C. F. Kettering, L. W. Shutts and D. H. Andrews, *Phys. Rev.*, **36**, 531 (1930).

because they illustrate in a rather striking manner the nature of standing waves.

The model of the one-dimensional diatomic lattice consisted of 28 blocks, which were made by cutting 2″ sections

FIG. 1.



Fundamental vibrations of one-dimensional lattice.

from broom handles. The blocks were jointed together by rather stout rubber bands passing through screw eyes placed at ends of the blocks. The "crystal," about 10 feet long, was "adsorbed" at one end to the ceiling and connected at the

bottom end to a reciprocating rod. The amplitude of motion of the rod was about one-half to three-quarters of an inch, and its speed could be controlled. The model was not quite comparable to a uniformly loaded string since the rubber bands at the top were stretched more than those on the bottom, due to the weight of the crystal itself. However, the only effect of this was to distort the position of the nodes slightly.

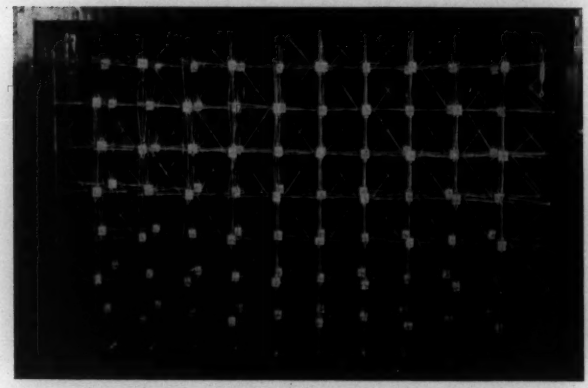
The photographs in Fig. 1 were obtained by taking time exposures of about 15 seconds while the blocks were in motion. The path of motion of each block is thus shown as a band. The first strip, a_0, shows the model at rest. The remaining strips illustrate in order the progressive shortening of the wave length as the frequency of the transverse vibrations increase. a_{13} is the fastest frequency where the neighboring particles are out of phase. The amplitude of vibration is shown to decrease markedly as the frequency increases, just as is to be expected.

We also found an additional mode of vibration as illustrated in a_R which effects a rotational oscillation or rocking motion of each of the blocks about its center of gravity. This was observed at a still higher frequency than a_{13}. It may be seen that the oscillation cannot be viewed as one of the coupled vibrations of the loaded string, since the oscillation dies out as we move away from the point where the vibrations are impressed and no vibrations of lower frequency were found for this type. With stronger coupling between the particles this may not be so. Probably for the coupling found in molecular crystals the rotational oscillations may be viewed in the first approximation as having but one frequency.

MODEL OF SOLID NEON.

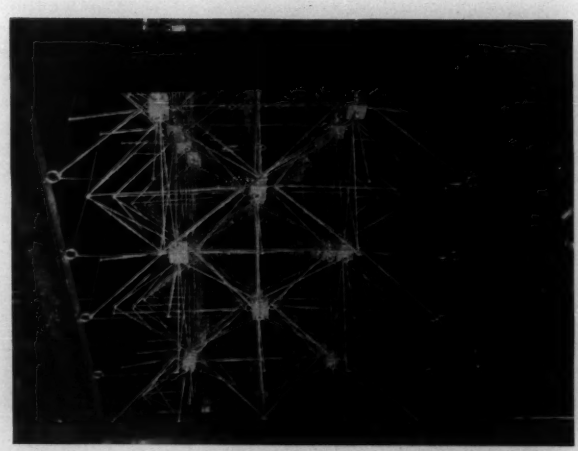
The mechanical model of solid neon is shown in Fig. A. It consisted of fifteen unit cells and contained 105 blocks. These blocks served as "neon atoms" and were wooden cubes of about one-inch edge. Each block had a small screw eye placed in the middle of each face. The design of the crystal followed the x-ray analysis of solid neon which shows it to be face-centered cubic. The forces holding the atoms in their equilibrium positions were represented by elastic bands made of pure gum rubber. The "crystal" was mounted in a

FIG. *A* 1.



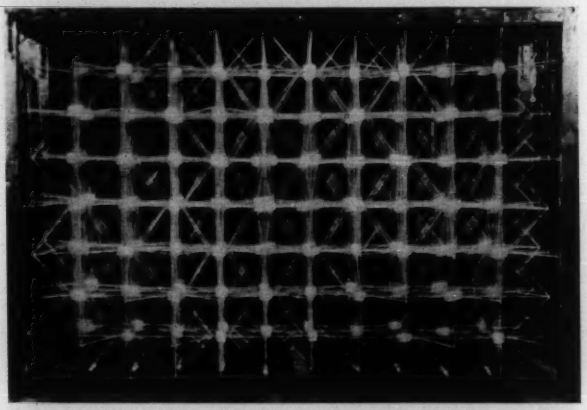
Neon crystal at rest.

FIG. *A* 2.



wooden frame 2 feet × 3.5 feet × 5 feet, and piano wire was stretched at definite intervals in this frame to serve as supports for the elastic bands. There were twelve elastic bands joining each block to its twelve immediate neighbors, and six elastic bands of one-half the strength joining each block to its six next closest neighbors. Approximately a thousand elastics were used in the model. The forces between more distant neighbors are so weak that they can be neglected. Figure *A*-2 shows a photograph looking down one of the

FIG. *A* 3.



All blocks going in same direction 460 r.p.m.

symmetry elements of the model and presents a realistic view of the "forces" of a crystal lattice.

When this model was agitated mechanically by a variable speed reciprocating rod and studied under the light of a stroboscope, the various types of motion could be observed in a striking manner. The reciprocating rod was attached to the center of a rigid rectangular framework so as to impress plane waves down the length of the crystal. As the speed of the motor was increased nothing happened to the major part of the crystal until a speed of about 460 r.p.m. was

FIG. *A* 4.

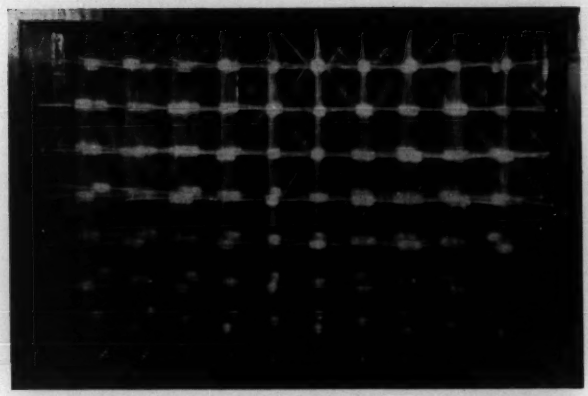
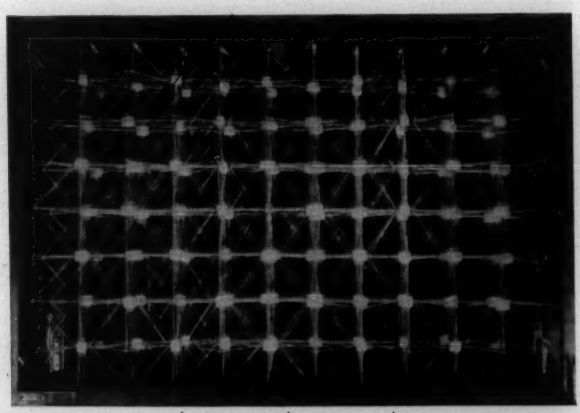
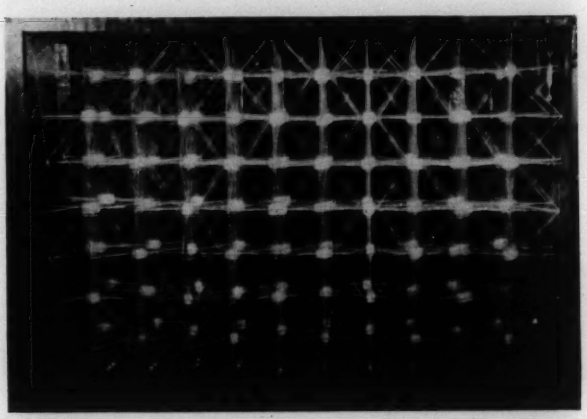


FIG. *A* 5.



attained. At this point, all the blocks moved in the same direction, the photograph of the motion under steady illumination being shown in Fig. *A*-3. With further increase of speed this motion died out, and at 575 r.p.m. the motion in Fig. *A*-4 was obtained where a node occurred in the center and the two parts of the crystal moved in towards the center. An interesting phenomenon occurred when the resonance points for these lower vibrations were attained. The speed of the

FIG. *A* 6.

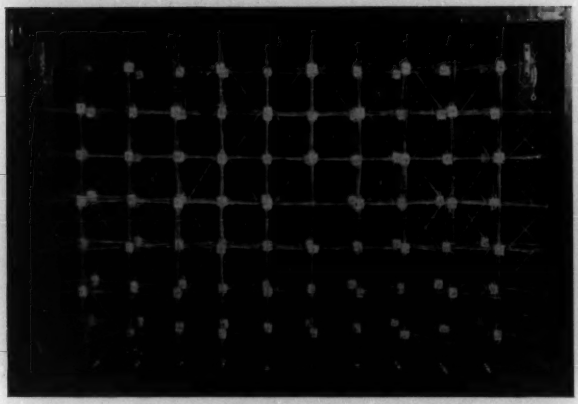


Alternate columns in opposite phase.

motor driving the agitator was controlled by the resonance vibration so that the current through the motor had to be increased several fold in order to increase the speed. This, of course, is just another example of the principle observed on the quartz crystal resonator which is used to control the frequency of an electrical circuit. Figures *A*-5, *A*-6 show still higher modes of vibration and Fig. *A*-7 shows the inactivity of the crystal at speeds too high to be in resonance.

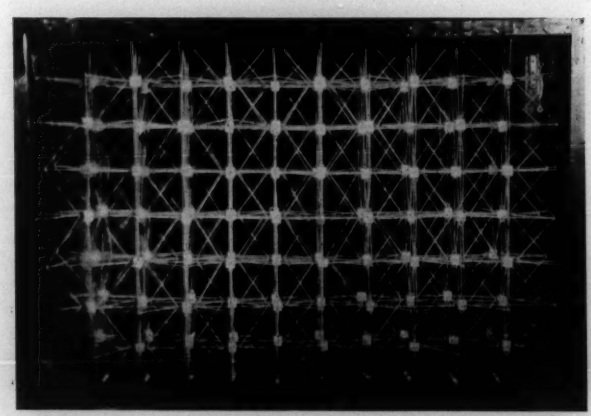
In order to observe the isotope effect one of the blocks in the center of the "crystal" was removed and a much heavier block inserted. When the model was then agitated, the

FIG. *A* 7.



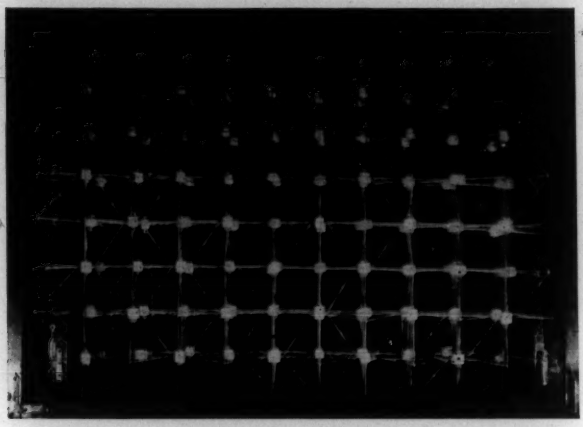
High speed, no response except small forced vibrations on left.

FIG. *B* 1.



Isotope (center) alone moving.

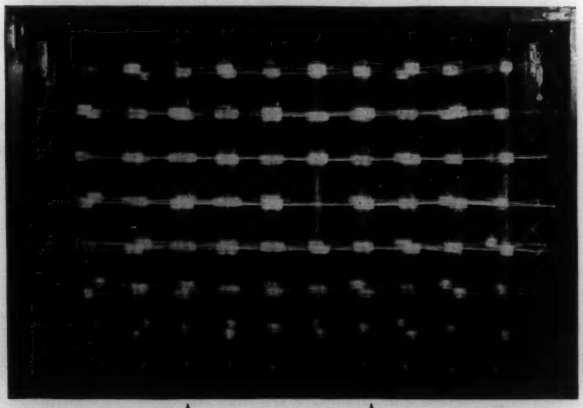
FIG. *B* 2



500 r.p.m.

Isotope moves against rest of lattice.

FIG. *B* 3.



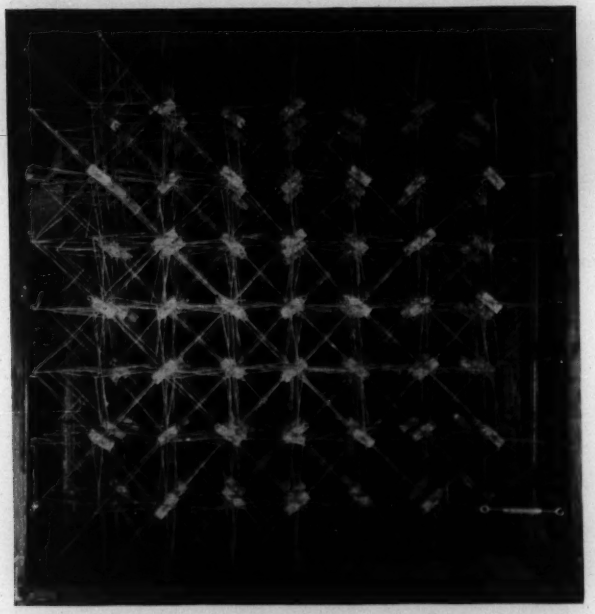
590 r.p.m.

Node Node

Note isotope not moving.

"isotope" alone was observed vibrating at a speed of 250 r.p.m., as shown in Fig. *B*-1. At a speed of 500 r.p.m. (see Fig. *B*-2) the crystal as a whole began to vibrate in the fundamental mode as in Fig. *A*-2, but the "isotope" moved in opposite phase to the rest of the lattice. At the higher speeds, as in Fig. *B*-3, the isotope remained stationary, while

FIG. *C* 1.



Nitrogen crystal at rest.

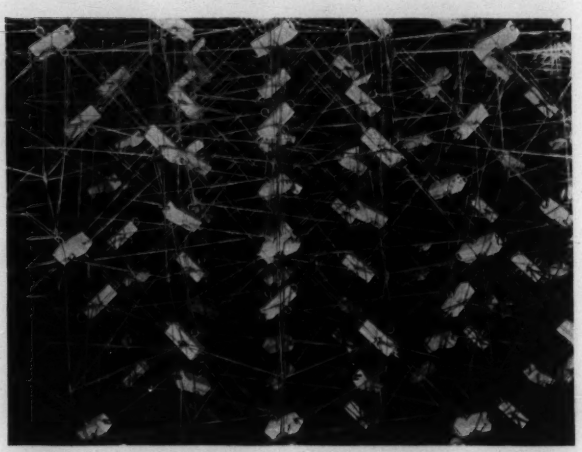
the crystal was in vibration around it. This behavior indicates that an isotope can vibrate independently if the mass difference is sufficiently large, as would be the case of deuterium. Also the presence of the "isotope" does modify the crystal vibrations, although this would effect only slightly

the thermal energy of a crystal which originates from a continuous band of frequencies.

MODEL OF α MODIFICATION OF SOLID NITROGEN.

The α-modification of solid N_2 is also a face-centered cubic lattice. The triple bond between the atoms of the nitrogen molecule is so much stronger than the forces between the molecules, that one can consider the molecules as rigid dumb-

FIG. C 2.



Close-up of N_2 crystal at rest.

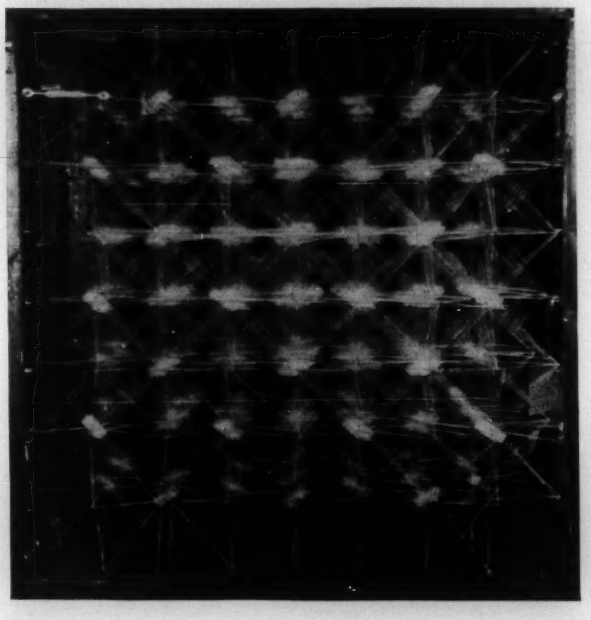
bells and represent them in the model by rectangular wooden blocks.

Figure *C*-1 shows the model which contains 122 blocks and makes up thirty-six unit cells. The blocks are oriented along the solid diagonals of the cube according to the diagram of the unit cell obtained from the x-ray measurements of Vegard.[2] Figure *C*-2 shows a closeup of the "crystal" at rest and shows the manner of attaching the rubber bands. When set in

[2] Vegard, *Zeit. f. Physik.*, **58**, 497 (1929).

motion the faster vibrations proved to be more complex and not easily untangled. Figure *C*-3 shows the fundamental mode and Fig. *C*-4 shows one of the higher modes of vibration. The difficulty with N_2 model was probably due to the fact that, with so few vibrating units, it was impossible to avoid

FIG. *C* 3.



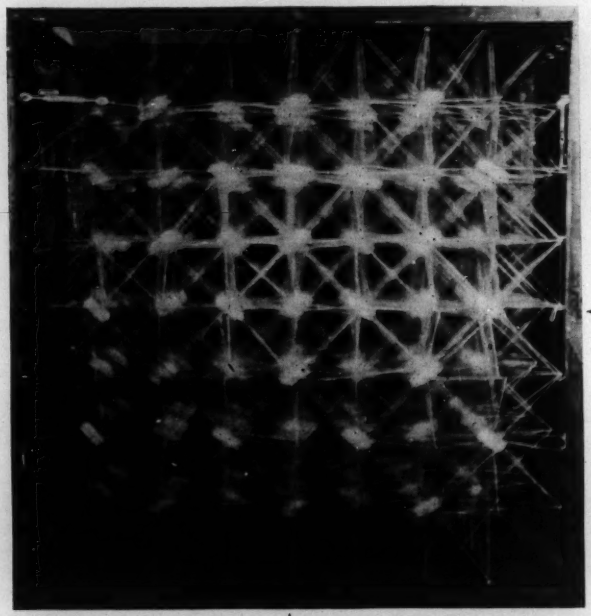
410 r.p.m.

Whole mass vibrating as unit in frame.

complicating the resonance vibrations by combinations with the variable forced vibrations, caused by fluctuations in the motor speed. The ideal mechanical model should be much longer and the oscillations excited by a fluctuating magnetic field or some similar force. The rubber bands should also be replaced by springs as a better representation of the forces set up by a displacement from the equilibrium positions.

In conclusion, we may say that the models have proved to be very useful as an aid in visualizing the various problems connected with the dynamics of crystal lattices. One can scarcely hope to attain an accuracy that will permit any

FIG. C 4.



rigorous proof of the nature of the lattice and its motions. On the other hand, as a stimulus to the imagination for both laboratory and class room we believe the models of this type may prove very valuable.

BALTIMORE, MARYLAND, October 1, 1934.

Natural Gas Turbine.—(*Power Plant Engrg.*, April, 1935.) In the Athletic Mining and Smelting Co., Fort Smith, Ark., a 45 hp. Elliott turbine driving a centrifugal water pump operates on natural gas. The turbine acts as a reducing valve, and exhausts low pressure gas for plant consumption. Gas pressure ranges from 40 to 50 lb. ga. and the exhaust from the turbine enters the low pressure gas main at about 8 lb. ga. pressure. The gas now passing through the turbine represents about two-thirds of the gas now needed for plant operation.

R. H. O.

Hardest Material Made from Borax.—(*Power Plant Engrg.*, April, 1935.) The hardest material ever produced by man, closely approaching the diamond, was announced recently by R. R. RIDGWAY of the Research Laboratories of Norton Co., Worcester, Mass., before the Electrochemical Society. Together with grinding powders, moulded forms and drawing dyes, he exhibited a beautiful gem, cut from the new material. Unsuccessful attempts were made to scratch this new material but it remained an example of industrial black diamond, manufactured from simple raw material from the earth with the aid of an intense application of electrical energy at temperatures and pressures exceeding those ever applied on an industrial scale. Boron carbide, which is unaffected by the strongest acids and alkalies, has a compressive strength of 260,000 lb. per sq. in., coefficient of expansion approximately two-thirds that of steel, is little affected by temperatures up to 1000° C., and is lighter than aluminum.

Boron is extracted from a brine solution taken from Searles Lake, Calif. and shipped to Niagara Falls, N. Y., where it is converted into an abrasive. After removal of the water of crystallization which accompanies the boric acid crystals, and which changes the physical character of the smooth crystals into a hard glass, quantities of the anhydrous glass are proportioned with petroleum coke. In a furnace which reaches a temperature approximately 5000° F. the oxygen is taken away from the glass and carbon substituted. The carbide melts and from this melt crystallizes boron carbide.

This new material has found an immediate use in the cutting and lapping of the new hard alloys known as cemented tungsten carbides which have replaced high grade tool steel in many industries. Experiments have shown it to be useful for many previously unsuspected purposes.

R. H. O.

STEAM TURBINES.

(A Review.)

BY

FRANCIS HODGKINSON,

Consulting mechanical Engineer,
Westinghouse Electric and Manufacturing Company.

(*Concluded from May issue*)

STEAM PRESSURES.

Steam pressures and temperatures have increased in steps from 150 lb. per in.^{2} to a maximum pressure of 1,400 lb. per in.^{2} with corresponding improvements in heat and steam consumptions. Increase in pressure has not presented difficulties. A proportionately higher blading constant is required because of increased heat drop. The maximum steam pressure is limited to parts of the turbine whose physical dimensions are small, so there has been no difficulty in securing adequate strength of the parts as far as the mere pressure is concerned.

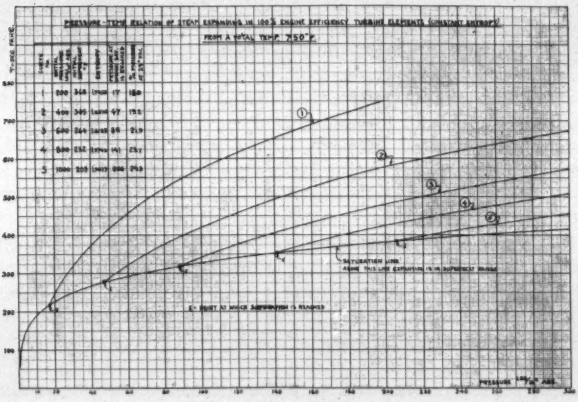
A problem arises, however, when pressures are increased. There is a greater deposition of moisture during expansion unless the amount of superheat is also increased. The higher the turbine efficiency, the greater is the quantity precipitated. If steam is expanded from a higher to a lower pressure by means of a nozzle of 100 per cent. efficiency, the available heat equivalent of work is in the form of kinetic energy. The heat contained in the steam leaving the nozzle is the total heat of the initial steam minus the heat equivalent of the kinetic energy and the expansion is said to be at constant entropy. If the kinetic energy could be absorbed by blades also at 100 per cent. efficiency, there would be no change in the total heat of the steam in passing the blades. Any losses in the blades however, would be at the expense of available work and would appear either as increasing the total heat of the steam or as residual velocity leaving the blade, or both.

The expansion in the nozzle within the superheated range

does not differ greatly in the respect of fall of pressure and temperature from that of a gas, but when the saturation point is reached, the character of the expansion entirely changes as though the steam endeavors to continue following approximately the laws of gases, which, if it did, its temperature would fall below that corresponding to the saturation pressure. The result is that some condensation takes place after the saturation temperature is reached and a proportion of the heat of evaporation is available for work instead of being thrown away in condenser cooling water.

The above may be clear from the curves of Fig. 18, in

FIG. 18.


PRESSURE-TEMP. RELATION OF STEAM EXPANDING IN 100% ENGINE EFFICIENCY TURBINE ELEMENTS (CONSTANT ENTROPY)
FROM A INITIAL TEMP. 750° F.
SATURATION LINE
PRESSURE LBS. PER SQ. IN. ABS.

which the pressure-temperature lines in the superheat range tend by their direction to go below the temperature of the saturation line.

In practice, the temperature actually falls temporarily below the saturation line. This is because the rate of expansion is rapid and time is required for coalescing the moisture particles. Possibly a dust particle is required to bring about the coalescence. This phenomenon is known as "super saturation" (not indicated on the curves).

It is understood that because of losses in the actual turbine, most of which appear as heat added to the expanding steam, the expansion is not at constant entropy but with increasing entropy. The point at which saturation occurs will, in the actual turbine, occur at a lower pressure and the final percentage of moisture will be less than shown on the curves.

The presence of moisture not only has a deleterious effect on blading, to which reference will be made later, but has a serious effect upon the efficiency of the turbine elements. Moisture, when precipitated, has practically no heat energy, so its particles travel through the turbine only by reason of entrainment by the steam. The velocity with which the particles are entrained varies as a function of the difference between the two densities, steam and water. Generally, moisture occurs only in the low-pressure ranges, so the velocity of the moisture particles is but a fraction of the steam velocity and even of the blade velocity. The result of this is that the moisture particles must be accelerated by the blading to the velocity of the blades, which absorbs energy from the blades, with consequential loss.

The first large turbine designed to operate with 600 lb. per in.^{2} pressure, superheated to 725° F., then regarded as a maximum safe temperature, was provided with steam reheating intermediate the initial and exhaust pressure, reheating the steam to 700° F. at 130 lb. per in.^{2} abs. at full load. The reheating was accomplished by providing heat-absorbing surface in certain of the boilers, the steam being carried from the turbine to the boiler room and back again. With these means, the moisture content in the exhaust steam approximated 7.4 per cent. Without the reheating, it would have been 15.5 per cent. Reheating, furthermore, according to its degree, adds to the available heat and enhances efficiency, but the principal purpose of reheating in this instance was to reduce the deposition of moisture. Reheating has, however, come to be regarded as a nuisance because of large piping to and from the boiler room. The steam volume contained in the piping and within the heating surface necessitated some special control apparatus to prevent the contained steam overspeeding the turbine in the event of the turbine being

relieved of load. For these reasons, when an additional machine of the same type came to be installed in the same station, reheating was not employed. It was arranged, however, to have steam extracted for feed heating. The parts of the casing where steam was extracted from the steam path were arranged in such fashion as to entrain as much of the contained moisture to the feed heater as possible. This is always carried out nowadays where extraction is provided for, and in large turbines drain means are additionally provided from the low-pressure steam path where the steam is wet, such as was shown on the section of the Philadelphia Electric machine (Fig. 14). Usually these drains lead directly to the exhaust chamber. The moisture particles maturally distribute themselves chiefly at the outer radius of the steam path because of centrifugal force, thus lending themselves to draining from the periphery of the steam path.

Reheating is used in all the installations of still higher pressures, 1,200 lb. per in.^{2} and above, but in all these cases, a high-pressure system has been superimposed upon an existing power system, i.e., a high-pressure back-pressure turbine is installed arranged to expand the steam from the high initial pressure to the pressure at which the existing system operates. The steam leaving the high-pressure turbine is reheated and then delivered to the steam main which supplies the existing turbines. In this way, some of the objections to reheating are eliminated; at least that of additional control apparatus. Because the reheating has been carried out at the initial pressure of the existing plant, the connecting piping to the reheater is relatively small.

Of late, engineers have endeavored to avoid reheating by going to the highest possible steam temperatures and employing pressures as high as may be, consistent with a reasonable percentage of moisture in the exhaust steam. It is generally believed that 12 per cent. moisture should not be exceeded.

Today, 850° F. is regarded as approaching the maximum safe temperature; notwithstanding, 900° F. is being offered. A turbine in one of the Detroit Edison plants has been operating successfully for some time with 1,000° F. steam of moderate pressure (385 lb. per in.^{2}). This particular turbine

was built in England. It is a tandem-compound turbine of 10,000 kw. capacity, operating at 3,600 r.p.m., so the respective turbine elements are of small physical dimensions, which renders the temperature problem much easier.

If a turbine can operate reliably with initial steam of 1,000° F., advantage might be taken of a pressure as high as 1,200 lb. per in.^{2}, when, without reheating, the moisture in the exhaust steam at 29-in. vacuum would approximate 11.4 per cent. without consideration of what moisture might be drained from the steam path.

STEAM TEMPERATURE.

Far more mechanical difficulties have been experienced because of temperature per se than because of pressure. Early in development, it was found that steam consumption was reduced about 1 per cent. for each 10° F. of superheat, but when even moderate superheat was employed, the phenomenon of "growth" of cast iron was encountered. This should not be confused with the later discovered phenomenon of "creep." Growth of cast iron appears to be an intercrystalline growth accompanied by loss of strength. It appeared in cast iron pipe fittings as well as turbine casings. It caused growth and a warping out of shape of the casing and blade interference and failure, or at least impairment of efficiency because of greater blade clearances. Nowadays, cast iron is not employed for turbine parts exposed to temperatures in excess of 450° F.

With ever-increasing steam temperatures, much lower calculated stresses must be employed because of reduction of ultimate strength and elastic limit of materials subjected to these temperatures.

Later, there developed the phenomenon of "creep." This is a more or less continuous stretching of materials whose rate increases with stress and temperature. It is a subject that has much exercised the skill of metallurgists during the last few years. It is believed by some that "creep" takes place with stress at any temperature but that at room temperature, it is not observable. This has brought about a time factor in strength calculations. Stresses are selected for important parts so that the creep will not exceed 1/100 of 1 per cent.

per year. "Creep" is of vital importance in control valve parts where failure because of sticking would be disastrous.

Bolts subjected to high temperatures, for example, should have sufficient length so that the elastic force due to tightening will remain sufficient over a predetermined period of time in spite of the bolt becoming longer because of "creep." It is sometimes customary for this reason, in Europe, to provide carefully designed spring washers underneath the nuts on short bolts.

MATERIALS.

The use of high temperatures has resulted in the development of numerous alloys. These invariably contain either nickel, chromium, molybdenum, tungsten, or silicon.

Many nickel-base alloys have been developed, but iron-base alloys (steel) are now more generally employed.

Many of the alloy steels containing chromium, also chromium and nickel, primarily developed for corrosion-resistance purposes, have high resistance to scaling, creep and deterioration. Tungsten, molybdenum, and silicon are frequently added for specific purposes. Molybdenum improves resistance to corrosion and embrittlement; it increases machinability, reduces friction between unlubricated surfaces and generally increases strength. Silicon also improves corrosion resistance and reduces oxidation.

Of late, more attention has been given to the development of alloy steels of comparatively low alloy content and several steels have been developed that have excellent load-carrying ability at high temperatures. The chromium-molybdenum-silicon steels are valuable.

An important consideration is the selection of steels or alloys for high temperature application is that of stability. Some alloys and steels possessed of desirable properties when new, may lose these properties and become embrittled or develop lower resistance to "creep."

There is yet another phase to the temperature problem, which has manifested itself. It is due to the amount of the superheat above the saturation temperature rather than the actual temperature. The walls of any chamber containing saturated steam are obviously at substantially uniform temperature even though there is radiation and some conden-

sation taking place, whereas with superheat, there may be laminations of steam having differing temperatures, which result in differing linear expansions, producing distortions. This has only required recognition and some ingenuity in design to maintain uniformity of section, as measured circumferentially, of the turbine, the avoidance of external stiffening ribs, etc., and arranging that in any cavities within the turbine, there is at all times ample velocity of flow and no stagnation.

Of course, proper provision must be made for the relative linear expansion of all the parts.

Steam temperatures in modern practice are higher than the fire point of lubricating oil. This requires that oil systems be arranged so that with any leakage there can be no possibility of spillage on to parts containing superheated steam. When servo-motor devices must be located above steam valve parts, a double pumping system is employed, one for lubricating oil, the other for the servo motors, in which latter, an inflammable fluid is employed. "Aroclor" has served for this purpose. It is prepared by chlorination of diphenol. Conflagrations have occurred both here and in Europe because these precautions have not been followed.

EXHAUST PRESSURE.

At the inception of turbine construction in this country, it would have been difficult to purchase a condenser of any kind that would produce more vacuum than 25 or 26 in. There had been no demand because the average reciprocating engine would have shown little, if any, less steam consumption with higher vacuum. Because the turbine can be made to expand to any low limit of exhaust pressure, a demand was made for better performance. Condensers have been undergoing a continual and interesting development with eminent success. 29 in. vacuum is common practice and higher is employed when it is justified by the economics of the particular installation.

A 400-lb.-per-in.^{2}, 750° F. turbine may receive about 17 per cent. more available heat when operated with 29-in. instead of 26-in. vacuum, but the exhaust steam volume would be about 3.8 times as great, requiring correspondingly greater

blade areas. Condenser development has therefore contributed greatly to the economies of turbines, but has also added greatly to cost. The 165,000-kw. turbine for the Philadelphia Electric Co., for example, passes over 12,000,000 cu. ft. of steam per minute to the condenser at full load. This volume may be visualized by realizing it corresponds to a sphere 284 ft. in diameter.

GENERATOR SPEEDS.

Among the most important factors in increasing reliability and reducing energy costs, the latter perhaps second only to increases in steam temperatures and the introduction of feed heating by extraction, has been the development of electric generator design.

It has already been pointed out how the earlier turbines were limited as to efficiency because of the low rotative speeds for which they had to be designed. Electrical engineers have since found their way to progressively increase generator capacities at a given speed up to some 150 times as great.

This increase has been due, in part, to the development of voltage regulating devices when generators could be designed for greater inherent voltage variation with constant speed and excitation.

A limit to generator capacity is the ability to liberate heat, the result of losses. The smaller the physical dimensions, the smaller is the radiation area. Improvements in ventilating means, including better fans and closed cooling systems, have been another factor.

The capacities of modern generators have now reached a point that about corresponds with the maximum capacity at the respective synchronous speeds for which the low-pressure elements of condensing turbines can be designed.

Generator development has permitted the turbine designer to increase efficiency by raising velocity ratios from about 60 per cent. to the optimum, which is between 85 and 90 per cent., as well as reducing losses by increasing the area of the steam path.

It has been a means of reducing the physical dimensions of turbines, which not only reduces cost, but increases

reliability because the smaller structure is less subject to distortion. The smaller the structure, the higher is the operating temperature that may be employed with safety.

The development of tooth gearing has enabled turbines to operate at their desirable speed driving direct-current generators and other slow-speed machinery, also in the case of driving small capacity alternators operating the turbine at higher than any synchronous speed.

BLADING.

Methods of blade construction, their fastenings and their forms have been undergoing continuous development. Reaction blading development has progressed in this country from the stage where the blade passages were formed by sawing slots in a brass strip, the flat blades thus formed being bent to a curve, the strip then bent and caulked in place.

The first efficient reaction blades comprised separate blades and spacers. The blades were of a copper-zinc alloy, were drawn to the desired shape and cut to length. The spacers were of carbon steel similarly drawn but to complementary shape, and cut to length. These were alternately set in slightly dovetailed grooves and caulked in place. This construction was regarded as satisfactory, although the blades were held in place by little more than friction.

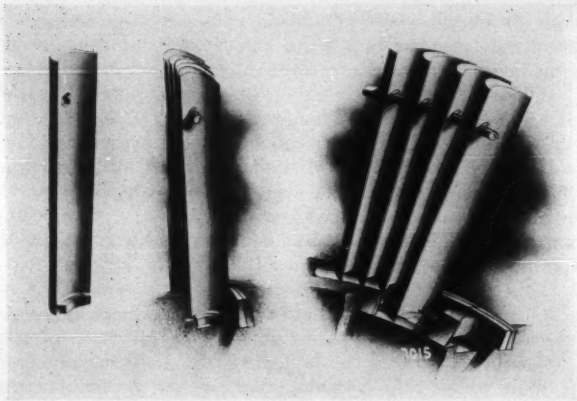
This form was modified in 1912 to that shown by Fig. 19.

The blade form and method of manufacture remained substantially the same. The innovation consisted of providing the spacers with dovetailed sides fitting in corresponding walls of the carrying groove. An overhanding foot was upset at the bottom end of the blade, which came under the spacer and fitted into a subsidiary groove in the floor of the main groove. By this means, the blading was locked in place, no caulking being required. For higher stresses and longer blades, spacers were eliminated, the blades having roots forged thereon.

With increases in blade speeds and blade dimensions, still stronger and better fastenings are required. With variations in steam temperature, the blades and their fastenings heat and cool more rapidly than the relatively massive rotor. When dovetailed holding means are employed, there is a

tendency for the roots to crush when heating rapidly and therefore become loose and move outward by centrifugal force a minute amount on becoming cool. This action may be progressive. Therefore, blades whose roots have abutments normal to the centrifugal force, as shown on Fig. 20, are preferred. The slide shows fastenings in the order of strength. The semi-circular sections below the blades are caulking pieces for the purpose of positioning the blades in their outermost positions so that there will be no subsequent movement when operated at speed. The side wedges are for the purpose of

FIG. 19.



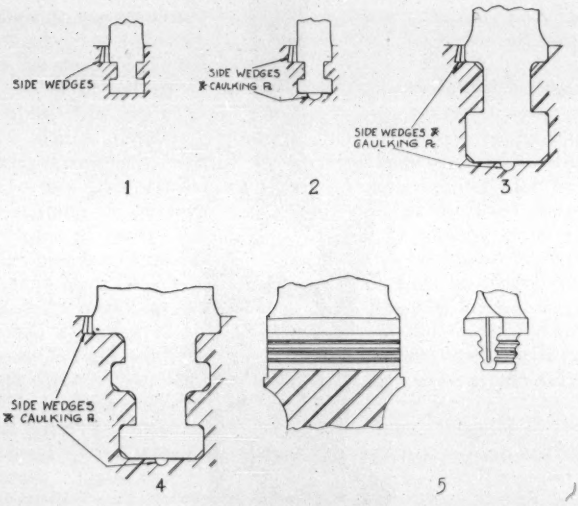
preventing vibration reaching the reduced section of the root where the section is reduced to a lower moment of inertia than that of the blade. This is now found to be unnecessary.

The design of the last fastening shown is clearer by means of Fig. 21. It is an invention on the part of Miss Bach. Though costly, it is believed to be a fastening of the maximum possible strength. It will be noted there are no eccentric loadings. It is not applicable to attachment to the surface of a drum. The blades are inserted laterally in curved slots at the outer edge of the disc.

The extreme low-pressure blades of large capacity turbines have a warped form. The velocity at the tip may be double that at the base, which requires that the entrance angle vary throughout the length of the blade, which is costly to produce.

Early difficulties with blading were due to breakage because of vibration. It was thought this was principally due to the low fatigue resistance of the non-ferrous alloys which were employed.

FIG. 20.

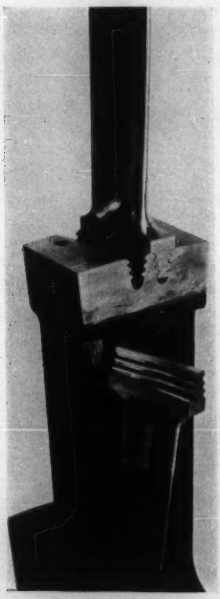


Steel was substituted with reduction of blade breakage, but corrosion then became a problem. This occurred principally at the dew point, that is, where moisture is first precipitated. The principal cause of this was the entrainment of atmospheric air with the feed water, which not only affected the blades but occasionally, with high oxygen content, produced severe corrosion of the casing and rotor. This brought about the development of deaerators which greatly reduced corrosion. Deaeration is usually accomplished by boiling

the feed water at a point between the condensate and feed pump by means of steam extracted from the turbine, condensing the portion of steam that is evaporated, and venting the liberated non-condensible gases to atmosphere.

Corrosion of steel blades was first ameliorated by the use of a copperclad steel, and later, more effectively, by the use

FIG. 21.



of an extremely low-carbon electric furnace steel containing 4 to 5 per cent. nickel.

Exhaustive metallurgical research to discover a material having strength, fatigue limit, and low creep limits under high temperature, together with non-corrodibility, has resulted in the development of a form of low-carbon stainless steel containing principally

Carbon..... 0.12 maximum
Chromium..... 11.5 to 13.0%

It is readily understood that a blade anchored at the root with its end free is subject to the same kinds of vibration as a tuning fork. This requires that the free ends of the blades be braced together to raise the natural vibration frequencies to a maximum degree. The form of bracing and its best location have been the subject of years of experimentation.

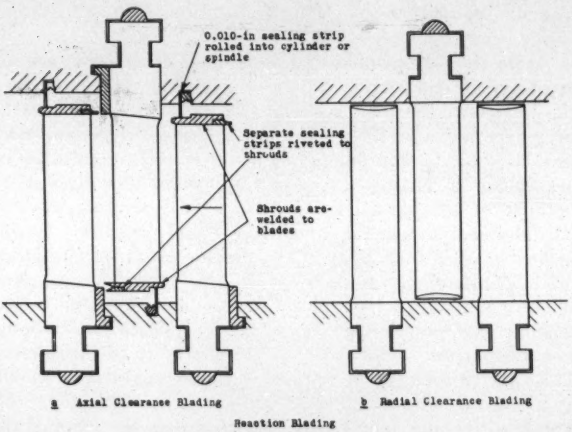
The various modes of vibration of individual blades and blade groups required study. Their many natural frequencies must be remote from any forced vibration, such, for instance, as the speed of the machine.

With the advent of the extreme blade speeds that are now employed in condensing machines, a serious wearing away of the blades at the inlet edges of the last rows of blades has been experienced. This is not an erosive effect such as might be caused by a scrubbing action of the moisture particles, but a spalling or pitting, the result of intense localized stress because of the blades striking the slowly moving moisture particles in an atmosphere of extremely low pressure. Several means have been tried to prevent this, such as chromium-plating, nitriding, etc. The best preventive known is to shield a portion of the blade with a material of the highest possible yield point regardless of other physical characteristics. For this purpose, "Stellite" has been found to be satisfactory. This is a cintered combination of about 50 per cent. cobalt, 30 per cent. chromium, and 15 per cent. tungsten. The "Stellite" is silver-soldered to the blades in the form of thin strips. These strips may be replaced in the field if necessity requires.

Attention has been given to reducing leakage in reaction turbines by reducing blade clearances. This is also important in single-row impulse elements since it has been found that efficiencies are improved by combining with the impulse effect, some reactive effect. Originally, with reaction turbines, the clearances over the tips of blades were made as small as possible consistent with unavoidable linear expansions and distortions of the casings due to heat. This is shown at the right of Fig. 22. For years, it has been the practice to thin the tips of the blades to about 0.01 in. thick, so that

the thin tip would wear in the event of accidental contact. Later, a system called "end-tightening," in which the restriction to leakage is axial instead of radial, was introduced by Parsons. The latest form of this, as employed by the Westinghouse Co., is shown at the left of Fig. 22. The blades are shrouded, the shrouds being provided with thin-edged strips of molybdenum stainless steel, which defines the axial clearance between it and a wearing strip at the base of the adjacent blade row.

FIG. 22.


0.010-in sealing strip rolled into cylinder or spindle
Separate sealing strips riveted to shrouds
Shrouds are welded to blades
a Axial Clearance Blading
b Radial Clearance Blading
Reaction Blading

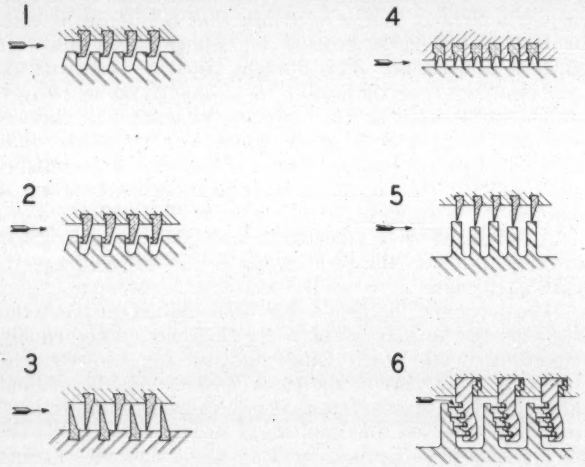
When end-tightening is employed, the thrust bearing has two positions with means of readily moving it from one to the other. With the thrust bearing in one position, the end-tightening may have ample clearances during starting and stopping, but with the machine under load and at operating temperatures, the thrust bearing is moved to its other position, when the end clearance is reduced to a few thousandths of an inch.

It has been found that leakage is further reduced by the radial-clearance defining strip shown. The thin-edged strips, it will be seen, may be replaced in case of injury.

The end-tightened construction is employed in the high-pressure portion only of a turbine, which is where clearance areas are more important. The construction is carried to a distance from the thrust bearing, within which the axial clearances, with the differing linear expansions due to heat, can be controlled. The remaining low-pressure blades are also shrouded and are provided with two radial clearance defining strips.

Many references have been made to labyrinth packings or dummies. They form one of the steam paths and are an important detail, particularly since, in the past, they have

FIG. 23.



Types of labyrinth packings or dummies.

not been immune from difficulty. Fig. 23 shows a number of forms.

No. 1 is the form originally employed. It was modified to the form shown at 2, so that the thin edges might wear in the event of accidental contact. It was one or other of these two forms which has been referred to as having given trouble

in the application to single double-flow machines where the labyrinth was remote from the thrust bearing. This, as stated, resulted in the development of a radial-clearance type, such as shown at 3, 4 and 5. While these types would have greater clearance than a properly adjusted axial clearance type, they permitted ample axial displacement. The object of the deep groove shown in No. 5 was to provide a more equal distribution of heat to the body of the rotor, in case of heat being locally generated by friction due to contact.

Many other forms of labyrinths have been developed both here and abroad.

With the introduction of end-tightened blading and the possibility of maintaining close axial adjustment in the blading, it is obvious that a labyrinth that is intermediate the blading and the thrust bearing can be maintained in at least as close adjustment. This brought about a reversal to the axial clearance type, the latest form of which is shown at No. 6.

The strips defining clearance are of a form of stainless steel containing molybdenum, about 0.01 in. thick. This material as stated, has low friction coefficients when unlubricated and has the faculty of wearing away in the event of contact.

An objective in a labyrinth packing, beside close clearances, is to obtain the greatest number of labyrinths in the least axial length.

The foregoing discussion has been limited to the steam paths of the turbine. There are, however, other equally important items which enter into turbine constructions. Among these are: Stator and rotor constructions, journal and thrust bearings, speed-responsive governor mechanisms, shaft packing glands, and the balancing of turbine rotors, including the influence of supports on critical speeds, any one of which is of interest and could be the subject of a separate article. All of them are of importance to reliable and good working turbines and have been subjected to interesting development.

INDUSTRIAL APPLICATION.

Steam turbines have place in industrial plants but in a different form. An industrial plant cannot, or at least should not, be able to justify installing a steam power plant solely

for the purpose of supplying power, if power lines from a utility company's central station are available. The central station should be able to supply power for less price than the cost from relatively small industrial plants, but if the industrial plant requires steam for some process heating, the complexion entirely changes. Steam may be generated at some higher pressure and expanded to the desired heating pressure with little loss in its value for heating purposes and so develop for low cost what is called "by-product" power.

For instance, suppose heating steam is required at 100 lb. per sq. in. abs. and it is generated at 600 lb. per sq. in. abs., superheated to 800° F., and further, that the liquid condensate condensed in the process heating apparatus can be returned to the boiler without loss of heat. With a back-pressure turbine, 85 per cent. of the work of the boiler would be expended in the process heating, and 15 per cent. in the work of the turbine. With a thermodynamic accounting, the by-product power in the above example is obtained at a thermal efficiency of 94 per cent., excluding boiler room auxiliaries and boiler losses. The best the central station could do similarly is about 34 per cent. thermal efficiency.

Unfortunately, demands for process heating and power do not balance each other in practice. At times, either the heating demand causes more power to be generated than can be made use of or the power demand causes more steam to be supplied to the process than can be made use of.

A tremendous national saving could be accomplished if arrangements could be made for an interchange of power on an equal basis between the central station and the industrial plant, when the industrialist would install back-pressure turbines appropriate only to his heating requirements. This, however, cannot be easily brought about. The central station engineer regards power that can come into his lines from such sources as "dump" power, not "firm" power. He holds that he must have machines operating ready to supply his system demand without any reference to energy coming from industrial sources. His fixed charges are not reduced, so that the only value of energy he gets from an industrial source is a saving in fuel, which is a minor item of energy cost. However, there are a few instances where a utility company

has built a plant for the specific purpose of supplying large volumes of low-pressure steam to a neighboring industry, besides supplying his own lines with "by-product" power.

These conditions have brought about the development of various kinds of automatic extraction type turbines which discharge some of the partially expanded steam to a heating system, the remainder expanding to a condenser. An initial pressure and temperature are selected that will develop the desired power with the specified quantity and quality of steam going to the heating system.

Such machines can be made capable of developing full generator capacity, when the maximum quantity of steam, or none at all, is being extracted. Regulating devices automatically maintain constant pressure in the heating system as long as the power requirement is great enough so that with all steam being extracted, the heating demand is satisfied. Control devices to accomplish these and other objects have required no small degree of resourcefulness in design.

MARINE APPLICATION.

Steam turbines are now universally employed for driving the higher powered ships. Their only competition is internal-combustion engines of capacities up to about 2,000 hp.

Sir Charles Parsons, in the early stages of turbine development, foresaw the possibilities of steam turbine propelling machinery for ships, and he incorporated the Parsons Marine Steam Turbine Co. for exploiting his ideas. The construction of a small ship, the "Turbinia," was undertaken. She was 100 ft. long, 9 ft. beam, 3 ft. draft. The propelling machinery was designed during the period Sir Charles was stopped from the use of his parallel-flow patents previously referred to. The first installation comprised a single-case, radial-flow turbine, which was direct-connected to the propeller and was expected to develop 2,000 hp. at from 2,000 to 3,000 r.p.m. From a modern viewpoint, this was an impossible combination. The trials commenced in 1894. The foremost experts in propeller design were retained and many forms of propellers were tried, but all results were disappointing. Experiments were undertaken with model propellers which were revolved in nearly boiling water and their action observed by strobo-

scopic means, when the cause of the difficulty was seen to be cavitation.

The construction of new turbines was undertaken, this time dividing the steam expansion into three parallel-flow, single-flow turbine elements, each driving a separate propeller shaft. Each shaft carried three propellers, 18-in. dia., which revolved at 2,000 to 2,200 r.p.m. With this arrangement success immediately began to be attained.

At the Naval Review at Spithead in 1897, the "Turbinia" caused a sensation in naval circles. The speed reached was $32\frac{3}{4}$ knots, which was unprecedented for so small a vessel.

The "Turbinia's" success resulted in the British Navy placing contracts with the Parsons Co. for the propelling machinery for two destroyers, the "Viper" and "Cobra," which proved to be unfortunate ships. The "Viper" went ashore in a fog and was lost; the "Cobra" foundered in a storm in the North Sea.

The behavior of the turbines was in nowise reflected in these disasters, but they did not escape calumny. There was newspaper correspondence endeavoring to show that the "Cobra" broke her back in a seaway because of the gyroscopic forces incidental to the turbine rotors, which must have been because of a misunderstanding of the arithmetic of the gyroscopic couple.

These disasters were a serious setback to marine turbine development, so, in 1902, the building of a destroyer, the "Velox," was privately financed. Following the trials, she was taken over by the British government.

More ships, naval and mercantile, were quickly undertaken thereafter and licenses were extended to nearly all the navies in the world.

The first turbine-driven passenger ship of real importance was the Cunard Liner "Carmania," in 1904. This installation was intended to develop experience because of the decision of the Cunard Co. to engine two new projected liners, the "Lusitania" and the "Mauretania," with turbines. The latter were built in 1907. The reason for this decision has been said to have been because of difficulty in obtaining large enough crankshaft forgings.

Too much cannot be said for the engineering skill shown

in the construction of the machinery of the "Lusitania" and the "Mauretania." The total horsepower was 68,000 and the speed 180 r.p.m. This low speed involved turbine structures of enormous dimensions. The low-pressure rotors were $11\frac{3}{4}$ ft. in diameter, 48 ft. long, and weighed 280,000 lb. What greater tribute could be paid to the engineering of the "Mauretania" than to point out that more than 20 years later, she gave the then latest big turbine ship, the "Bremen," propelled by geared turbines, a run for the blue ribbon?

As long as turbines and propellers were direct-connected, and the speeds of both of them compromised, the turbine could only compete with the reciprocating engine in high-speed ships. Because of the physical dimensions of the turbine, steam pressures much in excess of 150 lb. per in.^{2} could not be employed. To employ superheat would have been a risk because of distortions.

In 1916, high-power reduction gears were proposed by J. H. MacAlpine. By 1919, success was demonstrated, both here and in England, and the scope of the marine turbine was enlarged, so that it would apply to all sorts of ships. Both turbines and propellers could be operated at their best speeds, and the design problem was tremendously simplified. Higher pressures and particularly higher superheats could be employed with safety.

I am sure that any engineer of today would lose nights of sleep were he called upon to construct direct-connected turbine machinery for a "Mauretania," but would not be distressed in constructing high-speed, geared turbine machinery of high efficiency for any output.

There have been disputes respecting the relative merits of turbines either geared or with electric transmission; Diesel engines, either direct-connected, geared, or with electric transmission. No discussion of the relative merits is attempted, but each has its place. The selection, however, has not always been the best.

THE FUTURE.

Further increases in the heat efficiency of power stations are possible, but it is the total dollar cost of power, not the efficiency, that is all-important. A computation of how much

increased capitalization can be justified for a given increase in heat efficiency shows that it is trivial when proper allowances are made for fixed charges. A 10 per cent. reduction in fuel cost over present-day best practice, which may amount to a large annual sum, will justify only something of the order of $7\frac{1}{2}$ per cent. increase in capital expenditure.[1] If the advantages of betterment are divided between vendor and vendee, as is customary, capital expenditures cannot be increased more than 3 or 4 per cent. for a 10 per cent. reduction in fuel, i.e., about $3.00 or $4.00 per kw. of capacity. The central station engineer, therefore, directs his attention more to reduction of prime cost than to improving efficiency. If he must follow his natural bent, "the sport of chase of the elusive Btu," he must accomplish improvements in efficiency at little or no increase in prime cost.

One means of increasing efficiency is by the employment of a binary-fluid cycle, in which two fluids are employed, one of which has a high enough temperature, at exhaust pressure to evaporate a second fluid. Various substances have been proposed for the higher temperature fluid, one employing mercury is thermodynamically sound and has been reduced to practice by the General Electric Co.

Much thought has been given lately to new forms of boilers capable of operating with higher pressures. The drum type of boiler is not only limited as to pressure because of the cost of large drums to resist the pressure, but also because the nearer the density of steam approaches that of water, separation becomes more difficult. At the critical temperature, 706° F., 3,226 lb. per sq. in. abs., for example, separation would be impossible because both steam and water have the same density.

Attention has been directed to a "once-through" boiler in which, water is forced into one end of a continuous tube system and high-pressure superheated steam discharged from the other. Such an idea is not new, but Mark Benson proposed operating such a boiler at the critical pressure or

[1] Present-day best practice taken as 12,000 B.t.u. per kw. hr.
Fuel, 14,000 B.t.u. per lb. at $4.00 per ton
Annual load factor..... 60%
Interest..... 6%
Life..... 10 years

higher, when there would be no ebullition in the transition from water to steam. The application of heat to water or steam at critical pressure or higher continuously raises the temperature without any stage of heat absorption without rise in temperature, as in the case with sub-critical pressure. He feared that without this feature, alternate slugs of water and steam would be driven through the tube system and the operation of the boiler would not be uniform. He provided a back-pressure valve which would at all times maintain at least critical pressure within the boiler regardless of flow.

An experimental boiler was built in England in 1923, but shortly thereafter, the exploitation was undertaken by the Siemens-Schuckert Co. in Germany, and lately the Westinghouse Company has acquired manufacturing rights.

Early difficulties were the burning of tubes that were exposed to the radiant heat from the furnace, the reason for which was not immediately clear, because in taking the boiler out of service because of a burn-out, the interior of the burned tube was found clean and without scale. It was finally discovered that the burning was due to reduction of rate of heat transfer because of salt deposits which went back into solution when water was circulated in taking the boiler out of service. The remedy was to arrange for the transition stage from water to steam or the last fraction of evaporation and some superheating to be carried out in a gas pass of less intense heat, afterwards completing the superheating in a pass of intense heat. Feed water is treated so that it contains soluble salts only, which can be removed merely by the circulation of feed water.

Because the boiler comprises only tubes of about 3/4 in. inside dia., extremes of pressure are no problem. The volume that is contained within the tubes is small as compared with a modern water-tube boiler, so the rupturing of a tube is of little consequence beyond interruption to service. The boiler may be regarded as a contribution to increased safety.

It has later been discovered that it is not necessary to operate this type of boiler at the critical pressure. It may be operated at any pressure, at least as low as 500 lb. per sq. in. Because there are no drums, there is little heat storage, which opens up the possibility of operating a plant with variable pressure and constant temperature. The

Mollier diagram discloses that under this condition, the heat drop to condenser pressure remains nearly constant for any initial pressure above 500 or 600 lb. per sq. in., and inasmuch as volume is inversely proportional to absolute pressure, a turbine steam path that is correctly proportioned for one pressure condition is equally correct for another. The internal efficiency of the turbine is therefore nearly constant for outputs from the maximum down to say 25 per cent. of maximum, with the thermal advantage of operation with extremes of high pressure.

With these extremes of pressure, reheating naturally becomes a necessity, which increases the available heat. By this system, unprecedented efficiencies may be obtained of the order of 34 per cent. thermal efficiency for the whole plant including all losses, say 19 per cent. better than the best present-day steam practice.

With this system, boiler and turbine will form a combined unit, the one adapted to the other. Feed water supply is regulated in response to the turbine speed and combustion regulated to maintain constant temperature. The turbine will be simplified in the respect that it will have but a single steam path. It will not be complicated with costly valve gear for nozzle grouping or for bypassing high-pressure elements during times of maximum load. The maximum pressure would be limited to that where the gain due to increasing pressure commences to be offset by diminishing efficiency of the high-pressure turbine element because of the decreasing volume of the steam. The greater the capacity and speed, the higher is the pressure that can be justified.

It seems that this system presents a means of materially improving efficiency with little, if any, increase in capitalization over present practice.

An immediate market advantageous to the electrical industry will be the superimposition of a high-pressure system on an existing power station, in the same manner as has already been carried out with lower pressures of 1,200 or 1,400 lb. per sq. in., when the capacity of existing plants may be increased at low prime cost from 50 per cent. to more than 100 per cent. and efficiency improved from 30 to 50 per cent., according to the condition of the existing plant.

New British Gas Burner.—(*Gas Age Record*, Vol. 75, no. 14.) An invention of A. R. Pearson of the South Metropolitan Gas Co., London is an improved gas burner for producing an intermittent flame. In the burner the air and gas mixture reaching a Bunsen tube is ignited and the flame is propelled at a speed slightly in excess of the linear velocity of the mixture at the nozzle of the tube. In this manner the flame, after burning for a more or less lengthened period at the tip of the nozzle, travels down the Bunsen tube, where it is extinguished. A fresh intake of gas and air mixture is ignited by a pilot light at the nozzle and the cycle is repeated, and so on at regulated intervals. The periodic duration of the flame and the interval between each flash is adjustable over a wide range, the action thereupon becoming automatic. The invention is without moving parts of any kind. The burner is particularly suitable for numerous uses, for example in various kinds of manufacturing operations.

R. H. O.

Cooling with Air from Tunnels.—(*Heating and Ventilating*, Vol. 32, no. 4.) Twenty-five years ago a restaurant located in the basement of a downtown building in Chicago first made use of tunnel air for ventilation by means of a shaft dug down to a tunnel through which air could be brought to it. Today there are some 30 users of this cooled air from the extensive freight tunnels under the city of which there are some 62 miles. The prevailing temperature in the tunnel is around 55° as an average, rising to as high as 65° in summer. With summer conditions found in Chicago, air from the tunnel can be used to provide a 10° to 15° drop in temperature.

The popular method of using the air is to pass it through a washer for discharging through the building, although dry filters are employed in some installations. Some mechanically operated oil filters are also in service.

Before issuing a permit to use tunnel air the Chicago Board of Health investigates the portion of the tunnel where the air shaft is to be located. The shaft inlet is not permitted unless that portion of the tunnel is found to be clean and free from dirt.

With the tunnels in use in so many instances and over so long a period it is surprising that there has been no appreciable temperature rise in them.

R. H. O.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

MEETING OF AMERICAN PHYSICAL SOCIETY.

The 198th regular meeting of the American Physical Society was held in Washington, at the Bureau on April 25 and 26, and at the National Academy of Sciences on April 27. In all, 134 papers were presented, two of which were by members of the Bureau's staff as follows:

The establishment and destruction of superconductivity at radiofrequency, by R. B. Scott, F. B. Silsbee, and F. G. Brickwedde.

A new phenomenon on the superconducting transition of tin and tantalum, by F. B. Silsbee, F. G. Brickwedde, and R. B. Scott.

The first of these papers described an experiment in which a tin wire 0.022 cm. in diameter was supplied simultaneously with direct current and with alternating current of 200 kilocycles per second and of such value that the circular magnetic field in the outer layers exceeded the critical value at one crest of each cycle but was less than critical at the other crest. If the resistance of the material followed these pulsations would it be expected that the flow of the alternating current would produce between the ends of the specimen a drop of potential of distorted wave form containing a strong component of double frequency? Such a double-frequency component of the expected value was found. It varied with the temperature and the magnitudes of the components of current in the manner to be expected. It may be concluded that the mechanism of superconduction can come into action or be destroyed within a few microseconds by a sufficiently large magnetic field.

An investigation of the effect of combinations of the variables, temperature, transverse magnetic field, and speci-

* Communicated by the Director.

men current, on the resistance in the transition range was described in the second paper. The most characteristic effect, noted when the current was large (several thousand amp./cm.^{2}), was that the passage from the superconducting to the normal resisting condition was accompanied by a spontaneous increase in resistance, occupying several seconds, followed by a slower return. This transient resistance was sometimes 75 per cent. of the normal. After such an effect had occurred, it did not occur again when the same conditions were reëstablished after a short interval. The combination of variables at which this effect occurred was, however, definite if the time interval was long enough or if the specimen had been cooled to a low temperature. The effect occurred in two tantalum specimens at approximately the same (apparent) current density. The tin wire required about 50 per cent. greater current density. For tin $H = (2I/r)$ connects, approximately, with specimen radius the currents and fields which acting alone (1) restore a given fraction of the normal resistance and (2) initiate the spontaneous rise. For tantalum the currents required were only 3 to 4 per cent. of the calculated values.

TWENTY-FIFTH NATIONAL CONFERENCE ON WEIGHTS AND MEASURES.

The Bureau takes pleasure in announcing that a meeting of the National Conference on Weights and Measures will be held on June 4 to 7, inclusive.

At the time of going to press it is not possible to publish a program of the Conference sessions. However, it is probable that specifications and tolerances for the following classes of liquid-measuring apparatus will be considered: Vehicle tanks; large-capacity petroleum meters (wholesale type); vehicle-tank meter installations; and computing liquid-measuring devices of the retail type.

Letters have been mailed to interested individuals and firms requesting suggestions concerning the subjects listed above or relative to specifications and tolerances for other classes of equipment upon which it is believed the Conference might well take action. Such comments should be sent to

F. S. Holbrook, Secretary of the National Conference on Weights and Measures, before May 31.

For the benefit of those who have not attended one of these meetings it may be stated that the National Conference on Weights and Measures is an organization composed primarily of State and local weights and measures officials which meets periodically at the National Bureau of Standards in Washington, to consider questions relative to weights and measures administration. One of its important functions is the development of codes and specifications and tolerances for commercial weighing and measuring devices. After such codes have been adopted, first tentatively and later in final form, they are recommended by the Bureau for promulgation and use by States and local jurisdictions. Papers on practical weights and measures subjects are presented and discussed at the meetings by State and local officials, by members of the Bureau's staff and well-qualified members of other Government agencies, and by representatives of outside organizations.

Representatives of manufacturers of weighing and measuring devices also attend the sessions. They are privileged to discuss questions involving their products, but do not vote upon the adoption of codes of specifications, resolutions, etc. Informative exhibits of newly developed commercial equipment and the demonstration and explanation of such equipment have become valuable features of the meetings.

No meeting of the National Conference has been held since the twenty-fourth meeting in 1931, because of the adverse economic conditions. As a result, the number of important matters scheduled for consideration this year is larger than usual.

Sessions of the Conference will be held on all four days; morning and afternoon sessions will be held in the East Building of the Bureau on June 4, 5, and 6, and a morning session and an afternoon session will be held at the hotel headquarters on June 7.

The executive committee of the Conference has selected the Washington Hotel, 15th and F Streets, N. W., as the hotel headquarters.

"FLOWABILITY" OF MOLDING SANDS.

The ability of a foundry sand to move under pressure applied by ramming, and to adjust itself so as to fill uniformly and completely all parts of a mold is a matter of considerable importance in the foundry. In lieu of a better name, the term "flowability," has been used to connote this behavior. Sands differ considerably in this respect. In coöperation with the committee on molding sand research of the American Foundrymen's Association, a study has been initiated at the Bureau to ascertain the relative merits of several methods proposed for measuring the flowability of molding sands. The Bureau has been supplied by a manufacturer of molding-sand testing equipment with an Ames dial type of instrument which can be attached to a standard rammer as a means of studying the relative behavior of molding sands. Comparison will also be made with the deformation values determined by the spring compression test machine developed at the Bureau several years ago for foundry sands.

METALS TO RESIST SMOKE.

Keen interest has recently been expressed by railway equipment engineers and by architects in the behavior of metals in atmospheres contaminated with smoke from locomotives. Both severe corrosion and abrasion may be involved. Overhead electrification equipment on railways using both electric and steam locomotives is subjected not only to the corrosive effect of dense smoke but also to the abrasive action of soot and cinders and to the still more severe abrasion arising when electrical contact shoes slide along metal parts which may be coated with soot films. Smoke ducts are usually necessary where steam locomotives pass directly under buildings, the bare metal in such ducts being exposed to severe corrosion. This is also true of steel bridge members over railroad tracks. As several problems of this nature have been brought to the attention of the Bureau's metallurgists in recent months, a review is being conducted of present available information on the subject. Smoke-exposure tests have not, however, been undertaken.

CORROSION SURVEYS.

One of the most effective means for reducing the loss occasioned by soil corrosion of pipe lines is by the proper selection and application of protective coatings at the time the line is constructed. The general use of effective coatings will, of course, reduce corrosion but in general the maximum saving will not be effected because protection is not necessary in all soils. Methods for repairing or reconditioning the corroded parts of the line have been greatly improved and some engineers believe the most economical way to combat corrosion is to lay the line bare and later to recondition and coat the badly corroded parts of the line. The use of a corrosion survey for locating the corrosive soils at the time the line is laid has been tried in some cases, but has not been generally accepted because of the feeling that the methods of estimating the corrosiveness of the soil are not sufficiently reliable.

The American Gas Association and the Bureau have coöperated in the development of a method which is a combination of three widely different methods that have been suggested by others, and the survey is carried out in such a way that the cost is very small. The methods consist in mapping the soil types and in determining the average acidity and average electrical resistivity of each type. A further advantage of the method is that the corrosiveness of the soil is expressed in terms of costs, so that coatings can be selected and applied in such a way that the total average annual cost of combating corrosion is reduced to the lowest possible amount. The methods have been tested on one old and rather extensive pipe line system and have been shown to be economical in this case.

SERVICEABILITY OF PLATINUM LABORATORY WARE.

The following is an abstract of a paper on the serviceability of platinum laboratory ware of various compositions, presented by Dr. Edward Wichers, chief of the Bureau's section on reagents and the platinum metals, at the meeting of the division of physical and inorganic chemistry of the American Chemical Society in New York on April 25.

At the present time two types of platinum alloys are being used for laboratory ware in the United States. One type, known as standard crucible platinum, contains 0.2 to 0.4 per cent. of iridium. The other contains 3 to 4 per cent. of rhodium. Since the introduction of the latter type, only a few years ago, the Bureau has made observations on its performance in service as compared with the older "crucible" platinum. So far no striking differences in quality have been observed. They are about equally constant in weight during prolonged ignition. The platinum-rhodium alloy has a distinct advantage in its greater ruggedness. On the other hand, its tendency to stain or discolor under some conditions of use meets with some disfavor. As yet there is no evidence as to the probable relative life of the two alloys.

The standard "crucible" alloy was adopted by manufacturers some twenty years ago after an investigation at the Bureau had disclosed that the amount of iridium then used in ware (up to 4 per cent.) caused excessive losses in weight when the ware was heated at temperatures above 1,000° C. More recent observations have indicated, however, that the iridium content need not be restricted quite so severely. Crucibles containing 0.75 per cent. of iridium are much more rugged than those containing 0.2 to 0.4 per cent. (if the weight and design are the same) and do not lose weight rapidly enough, even with free access of air, to cause significant errors in many operations of quantitative analysis. When such crucibles were heated in the flames of Meker-type burners, the loss in weight was almost exactly the same as that of the other two types (about 0.2 mg. per 25 ml. crucible in 4 hours at 1,100° C.). This difference in behavior is due to the virtual exclusion of oxygen from contact with the platinum.

The change in weight of platinum crucibles varies so much with the conditions of heating, as well as with the composition of the ware, that the only safe procedure to follow in work of high accuracy is to determine the changes which actually occur under the conditions of the experimental work. If one or two empty crucibles of the same type of ware are carried through the entire experimental procedure and used as tares during weighing, the necessary corrections are automatically made.

For dishes and other ware which is not heated to high temperatures for long periods, advantage may well be taken of the hardening effect of larger amounts of iridium. Two per cent. of iridium is suggested for small dishes (up to 150 ml.) and 5 per cent. for larger ones.

Fabrication of crucibles in such a way that both the bottom and the rim are thicker than the intermediate portion of the wall adds materially to the rigidity and strength of the ware. No evidence has been obtained thus far on the relative merits of different processes of fabrication. Service records show that the simple process of spinning is not objectionable.

If crucibles escape damage by contamination with foreign substances during use, they will eventually go out of service because of the development of inter-crystalline cracks. This embrittlement which comes with age is the only remaining serious fault of platinum ware. There is as yet no satisfactory explanation for the development of these cracks. A possible cause is the accumulation of impurities at grain boundaries, either as the result of slow and continuous contamination from gas flames or other outside sources, or of the gradual diffusion of small amounts of impurities which are originally present in the platinum. Sudden failure of a crucible in service is almost sure to be the result of some error or accident in the use of the ware, rather than a fault in its manufacture.

DISCHARGE COEFFICIENTS OF SQUARE-EDGED ORIFICES.

During the past 12 years a good deal of experimental work has been done on orifice meters, especially of the types extensively used in the natural gas industry, in which a square-edged orifice in a thin plate is held between flanges. In the greater part of this work air or gas has been the fluid in the test line. In more than half of these air and gas tests the indications of the "test meter" were compared to the indications of one or more "reference orifice meters." In the remaining tests the indications of the test meter were compared to those of some other device which could be used as an independent reference meter. Such devices were gas holders, flow nozzles, and weighing scales for the condensate

when steam was used as the fluid. Coefficients based on some of these latter tests have been used in commercial measurements with orifice meters.

More recently an extensive series of tests was made at Ohio State University, Columbus, Ohio, in which water was used as the fluid and the actual quantity flow determined with tanks and weighing scales. The results of these tests are now being used as the basis on which extensive orifice coefficient tables are being prepared.

It is a matter of much interest and value to know how well the tests with gas agree with those using water. The necessary comparisons have now been made at the Bureau on the basis of the Reynolds' numbers of the fluids. (The Reynolds' number is a product taking into account the dimensions of the orifice, the velocity of the fluid, the density of the fluid, and its absolute viscosity.)

A report of the comparison, prepared by Howard S. Bean was submitted last March to the gas measurement committee, natural gas department, American Gas Association, which committee has borne the major portion of the expense of tests with which the Bureau has been connected. A report on new coefficients was given by this committee at the meeting of the natural gas department, American Gas Association in Memphis, Tenn. May 6–9. Except for 3 orifice plates, which had defective orifice edges, the gas tests agree with the water tests well within the known experimental uncertainties. In several cases the agreement could hardly be improved upon.

THERMAL BEHAVIOR OF THE KAOLIN MINERALS.

The minerals of the kaolin group, when heated from room temperature to 1,000° C. or higher, exhibit two marked heat effects, (1) an absorption of heat from 450° to 680° C., and (2) an evolution of heat from 925° to 985° C. These effects and the chemical and physical changes which accompany them have been the subject of study for many years, not only because of their intrinsic interest, but because of their importance in relation to heat balance in ceramic kilns, the use of heat-treated clays as additions to portland cement and the production of aluminum from clay.

Evidence obtained at the Bureau in the investigation by X-rays of samples of the kaolin minerals and of synthetic $Al_2O_3-SiO_2$ gels which have been subjected to controlled heat treatments, shows that the heat absorption is related to the dissociation of clay into water vapor and an intimate mixture of amorphous Al_2O_3 and amorphous SiO_2, and that the heat evolution is caused by the crystallization of $-Al_2O_3$ from amorphous Al_2O_3. The presence of silica is of great importance in retarding the crystallization of $-Al_2O_3$ until a certain "critical temperature" is reached. RP792 in the May number of the *Journal of Research* should be consulted for the complete account of this work.

SPECIFIC REFRACTIVITY OF SOME GLASSES.

Certain data on the composition, index of refraction and density of some soda-silica glasses, either with or without added lime or alumina, were reported in *B. S. J. Research*, **6**, 993 (June, 1931); **9**, 799 (December, 1932); and **14**, 133 (February, 1935); Research Papers 320, 507, and 762, respectively.

Considering the applicability of the data to the formulæ of Gladstone and Dale, Lorentz and Lorenz, Eykman and Lichtnecker, the most satisfactory agreement was found to be in the formula of Gladstone and Dale, viz., $(n-1)/d = R$, n being the index of refraction for yellow light, d the intensity, and R the specific refractivity. Assuming the refractivity and density of vitreous (fused) silica as being 1.4587 and 2.2026, respectively (which are consistent with published values and with the Bureau's own data), it can be shown that R for any of the glasses studied can be computed from:

$$100R = (n-1)100/d$$
$$= 0.20835A + 0.19335B + 0.22435C + 0.20750D,$$

in which A, B, C and D are the percentages of silica, soda, lime and alumina, respectively, in the glass. The constants for A, B and C are in good agreement with those reported by Morey and Merwin in the *J. Optical Soc. Am.*, **22**, 657 (November, 1932).

Similarly, the constants for computing R for glasses containing potash and magnesia, based on unreported data, are 0.20185 and 0.21185, respectively. Computations applying the six constants given above to published data on optical glasses from German and other sources indicate that the constants for the oxides of lead, barium, zinc, and boron should be about 0.130, 0.130, 0.150, and 0.202, respectively.

STANDARD TESTS FOR ENAMELS—REFLECTANCE.

It was stated in Technical News Bulletin 213 (January, 1935) that the Bureau had agreed, at the request of the Porcelain Enamel Institute, to undertake the development of standard tests for enamels and enameled products, and that the first tests under consideration were to be those for reflectance, abrasion resistance, and acid resistance. In furtherance of this undertaking a tour of inspection of fifteen important laboratories located in the eastern part of the United States was made in March by a representative of the Bureau, in order to compare the methods in use and determine the causes of such discrepancies as exist between the results obtained in the different laboratories. In the case of the reflectance test, which is the first for which a tentative standard will be submitted, the variation in the results obtained at the different laboratories was attributed chiefly to the following causes, in various combinations:

(*a*) Some instruments were designed to include both specular and diffuse reflection in the reported reflectance values while others were designed to exclude the specular.

(*b*) Of the latter type, some were only partially successful in eliminating the specular reflection, especially on a wavy surfaced enamel.

(*c*) Some had glass shields in the optical systems which were so located that upon collecting dust they tended to deflect light into the field of vision not intended to go there.

(*d*) The reference standards were in some cases not satisfactory, specifically where magnesium carbonate was used for the purpose, since this material varies in reflectance from piece to piece and from time to time.

(*e*) No uniform practice with respect to light filters was in effect.

(*f*) Variations in design and calibration of the instruments were conducive to differences in results which can be corrected by the use of a series of standards covering a range of reflectance (instead of a single standard at one reflectance). An example is the non-linearity of the illumination current relation in photo-electric cells in the cases of some instruments using these devices.

The variation in results was surprisingly small in view of these sources of error, and plans are under way for supplying the needed reflectance standards, and eliminating other differences sufficiently to bring the results into substantial agreement.

MOLECULAR WEIGHT OF RUBBER HYDROCARBON.

Lacquers containing high viscosity cellulose nitrate, if shipped by train from New York, N. Y., to San Francisco, Calif., have an initial viscosity approximately 4 times as great as that of a similar lacquer, which is shipped to Cincinnati, Ohio. The vibration during shipment reduces the viscosity of the lacquer. If a mineral acid is added to a viscous rubber cement and the cement is exposed to sunlight, it quickly becomes fluid. The structures of the cellulose nitrate and of the rubber are changed, and the change presumably is accompanied by a lowering of the molecular weight. There is described in *B. S. J. Research*, **10**, 479 (April, 1933) (RP544) a method of purifying rubber hydrocarbon, the chief purpose of which is to maintain the structure of the rubber unchanged during purification. Subsequently the rubber is separated into two fractions by ethyl ether. Approximately 75 per cent. is soluble and 25 per cent. is insoluble.

Much work has already been done on the molecular weight of total rubber by many investigators and the values reported in the literature vary from about 300 to 82,000. Many of them were determined by observing the depression of the freezing point. They do not indicate the molecular weight of rubber in its highest physical aggregation, which is a condition of special interest to chemists who are investigating the synthesis of rubber. Determinations of molecular weight by freezing point depression are obviously unsuitable if the molecular weight is very high.

Drs. E. O. Kraemer and W. D. Lansing of E. I. DuPont de Nemours & Company, Wilmington, Del., have recently determined the molecular weight of an ether-soluble fraction, prepared at the Bureau. They used the Svedberg ultracentrifuge, and the method employs sedimentation-equilibrium, which is thermodynamically equivalent to the freezing point method, and, like the latter, is not influenced by the shape of the molecule.

The average molecular weight of the soluble rubber fraction is about 500,000. Prof. George L. Clark of the University of Illinois, who is investigating the X-ray diffraction patterns of soluble and insoluble rubber prepared at the Bureau, and is also examining crystalline rubber, some time ago deduced from data obtained in part by X-ray measurements that the molecular weight of cellulose is 500,000. Drs. Kraemer and Lansing have recently determined the molecular weight of cellulose by the Svedberg method and report a value of 500,000. Cellulose and the soluble rubber fraction therefore have comparable molecular weights, and they are said to have "giant molecules." As a result of the work of Kraemer and Lansing, chemists interested in the synthesis of rubber now have a definite goal, in the shape of a known molecular weight, for which to strive, in order to make synthetic rubber that is comparable to Hevea rubber. Their work was described in detail at the meeting of the American Chemical Society in New York City, April 22 to 26, 1935.

FIRE-RESISTANT DOPED FABRIC FOR AIRCRAFT.

The rapid growth of the aviation industry in this country has brought to the fore the problem of eliminating the fire hazard inherent in the cellulose nitrate doped fabric now commonly used to cover the wings and fuselage of service airplanes. The destruction of costly aircraft because of the accidental ignition of the flammable covering by the backfiring of the engine, the careless toss of a lighted match or cigarette, or the chance settling of a spark from a nearby flue has become too general an occurrence. An investigation was, therefore, undertaken by the Bureau with the financial assistance of the National Advisory Committee for Aero-

nautics to develop a non-flammable doped fabric for aircraft. The results of this study were presented by Dr. Gordon M. Kline at the meeting of the paint and varnish division of the American Chemical Society in New York on April 23 and will also be published in the May number of the *Journal of Research* as RP788.

The use of natural and synthetic resins and mixtures of synthetic resins with cellulose nitrate and cellulose acetate has been investigated. The resins do not tighten the fabric sufficiently to be satisfactory as airplane dopes. In general a 3 : 1 ratio of cellulose derivative to resin is necessary to attain satisfactory tautness. In this proportion even the least combustible resins do not markedly improve the fire-resistance of the doped fabric. No method has been found to fireproof airplane fabric doped with cellulose nitrate and maintain satisfactory tautness and weight requirements. An airplane covering with very good resistance to ignition can be obtained by the application of a 3 : 7 boric acid-borax mixture to airplane cloth and subsequently doping it with cellulose acetate. This doped and fireproofed cloth, containing approximately 5 per cent. of the boric acid-borax mixture by weight, will not burn in a horizontal or vertical position and is not ignited by lighted matches or burning gasoline.

Circuit Breakers for Boulder Dam Line.—(*Elec. Engrg.*, Vol. 54, no. 4.) D. C. PRINCE of the General Electric Co. describes the theory, construction, and tests of the new type circuit breaker to be used on this 275 Kv. transmission line 270 miles long from Boulder Dam to Los Angeles. To secure the maximum through power under fault conditions, the two parallel tower lines are united and sectionalized at two desert switching stations located respectively 90 miles from each end of the line. At each switching station and at sending and receiving stations four 2,500,000 Kva. circuit breakers are to be installed, so connected that in the event of a fault anywhere on the line, only one 90 mile circuit need be cut out. Power then will be transmitted over the remaining 90 mile single circuit and 180 miles of two circuit line.

The new oil blast breaker was developed for high speed operation, 3 cycles from initiation of tripping impulse to interruption of circuit; its small oil volume is 2500 gallons or about 1/10 that of an equivalent breaker of conventional design. The oil exposed to arcing is only about 210 gallons or 1 per cent. of that exposed in an equivalent conventional breaker. Two interrupting elements are provided, each containing four breaks and a piston to furnish the oil blast. A complete 3 phase unit of this design weighs approximately 110,000 pounds as compared with 290,000 pounds for a tank breaker.

While the interrupting rating of this 287 Kv. breaker is 2,500,000 Kva., in a test made on one break at a voltage 50 per cent. higher than one break can receive in service, 3800 amperes was interrupted.

R. H. O.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, MAY 15, 1935.

The stated monthly meeting of the Institute was called to order at three-thirty P.M. by the President of the Institute, Mr. Nathan Hayward.

The President stated that the minutes of the April meeting had been printed in full in the May number of the JOURNAL of the Institute, and that, if there were no objections, the minutes would stand approved as printed. No objection was offered and the minutes were declared approved.

The next item of business was the presentation, of Certificates of Merit and medals which had been recommended by the Committee on Science and the Arts, and the award of Certificates of Honorary Membership.

The order of the awards proceeded as follows:

Programme.

Trio—Andante and Allegro from Opus 2 . . . . . *Handel*

	Sponsor
Presentation of Certificate of Merit to	
GEORGE S. KELLEY, New York City, New York	Dr. Hepburn
Presentation of Longstreth Medals to	
EDMOND BRUCE, Bell Telephone Laboratories, Red Bank, New Jersey	Mr. Sellers
HOWARD D. COLMAN, Rockford, Illinois	Mr. Masland
and	
BURT A. PETERSON, Rockford, Illinois	Mr. Masland
PETER DAVEY, New York City, New York	Mr. Kavanaugh
KARL B. MCEACHRON, General Electric Company, Pittsfield, Massachusetts	Mr. Ellis
Presentation of Wetherill Medals to	
FRANCIS FERDINAND LUCAS, HON. SC.D., Bell Telephone Laboratories, New York City, New York	Dr. Cope
ROBERT E. NAUMBURG, New York City, New York	Mr. Levy
WILLIAM HAMILTON SHORTT	Mr. Stokley

Exeter, England
and
F. HOPE-JONES ..... Mr. Stokley
London, England
JAMES EDMOND SHRADER, PH.D. ..... Mr. Bates
The Drexel Institute
Philadelphia, Pennsylvania
LOUIS BRYANT TUCKERMAN, PH.D ..... Dr. Wright
Bureau of Standards
Washington, D. C.
HENRY ELLIS WARREN ..... Mr. Bonine
Ashland, Massachusetts

Trio—Capriccio . . . . . *Haydn*

Presentation of Clark Medal to *Sponsor*
FREDERICK JOSEPH WEST ..... Mr. Klumpp
Manchester, England

Presentation of Levy Medal to
HAROLD L. HAZEN, SC.D. ..... Dr. Crampton
Massachusetts Institute of Technology
Cambridge, Massachusetts

Presentation of the Franklin Medal and Certificate of Honorary Membership to
ALBERT EINSTEIN, PH.D., F.R.S. ..... Dr. Palmer
Institute for Advanced Study
Princeton, New Jersey

Presentation of the Franklin Medal and Certificate of Honorary Membership to
SIR AMBROSE FLEMING, M.A., D.SC., HON. D. ENG., F.R.S. . . . Dr. Palmer
Emeritus Professor, University of London
London, England
Received by Sir Ronald Lindsay, G.C.M.G.
His Britannic Majesty's Ambassador to the United States

Trio—Entr'act from "Rosamunde" . . . . . *Schubert*

Papers.

"The Thermionic Valve in Scientific Research"
SIR AMBROSE FLEMING
Read by the Secretary of The Franklin Institute
"Physics and Reality"
DR. ALBERT EINSTEIN

HOWARD MCCLENAHAN,
Secretary.

(An extended account of the proceedings of Medal Day will be published in an early issue of the JOURNAL.)

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, May 8, 1935.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 8, 1935.

MR. CHARLES H. MASLAND, 2D, *in the Chair.*

The following reports were presented for final action:

No. 2997: Electric Resistance Element.

This report recommended the award of the John Price Wetherill Medal to Mr. Albert L. Marsh, of Detroit, Michigan, "In consideration of the contribution of a material which has proved of extreme importance to the electrical industries."

No. 2999: Magnaflux.

This report recommended the award of Edward Longstreth Medals to Major William E. Hoke, of Baltimore, Maryland, and Dr. A. V. deForest, of Southport, Connecticut, "In consideration of the new application of certain long-known principles to fill the need for a ready means of detection of hidden defects, primarily at or near the surface of magnetic materials, and of the development of means for the commercial application of this method to present day engineering problems."

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

RESIDENT.

DR. EDWARD G. RAMBERG, Junior Engineer, RCA Manufacturing Company, Camden, N. J. For mailing: 117 East Walnut Street, Merchantville, N. J.

STUDENT.

MR. ALEXANDER BECK, 1837 South Fifth Street, Philadelphia, Pa.
MR. LEONARD BISCH, 485 Gerhard Street, Philadelphia, Pa.
MR. RUSSELL L. CARR, 2424 South Seventh Street, Camden, N. J.
MR. SPENCER WARD GREIMS, 2202 Pine Street, Philadelphia, Pa.
MR. WILLIAM L. MCCLINTOCK, JR., 4931 Osage Avenue, Philadelphia, Pa.
MR. FREDERICK REINITZ, 3014 North Marshall Street, Philadelphia, Pa.
MR. FRANCIS A. WODAL, 6550 Cedar Avenue, Merchantville, N. J.
MR. JESSE E. WOOD, 5542 Delancey Street, Philadelphia, Pa.

MUSEUM MEMBERSHIP.

FAMILY.

MR. HENRY PAUL BUSCH, 1006 Spruce Street, Philadelphia, Pa.

INDIVIDUAL.

MR. WILLIAM F. S. BEESE, 2133 North Twenty-eighth Street, Philadelphia, Pa.
MR. WALTER W. HAVILAND, Friends Select School, Parkway and Seventeenth Street, Philadelphia, Pa.

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Miss R. Beatrice Miller, 6407 Overbrook Avenue, Philadelphia, Pa.
Mr. Charles W. Schlipf, 3751 Pulaski Avenue, Philadelphia, Pa.
Miss Margaret Rosborough, 1421 Arch Street, Philadelphia, Pa.
Mr. Adrien W. Vollmer, 1007 Commercial Trust Building, Philadelphia, Pa.

STUDENT.

Mr. Milton Apothaker, 5348 Lebanon Avenue, Philadelphia, Pa.
Mr. Anastas Bandy, 5924 Jefferson Street, Philadelphia, Pa.
Mr. Herbert Billman, 131 Delphine Street, Philadelphia, Pa.
Mr. Robert H. Bram, 2107 West Erie Avenue, Philadelphia, Pa.
Miss Frances Cohen, 3216 West Turner Street, Philadelphia, Pa.
Miss Emma Fickhardt, 3216 West Turner Street, Philadelphia, Pa.
Mr. Harry J. Hatch, Jr., 13 Meredith Avenue, Garrett Hill, Pa.
Mr. P. James Moore, Radnor, Pa.
Mr. Robert Muller, 3716 North Eighth Street, Philadelphia, Pa.
Mr. Richard F. Nathan, 1928 West Erie Avenue, Philadelphia, Pa.
Mr. Charles G. Nicholson, 6607 North Seventh Street, Philadelphia, Pa.
Mr. Robert R. Pinkus, 2434 South American Street, Philadelphia, Pa.

CHANGES OF ADDRESS.

Dr. E. A. Eckhardt, Box 2038—Main Post Office, Pittsburgh, Pa.
Mr. Bryon E. Eldred, 51 East Forty-second Street, New York City, N. Y.
Mr. Carl G. Barth, 900 North Sixty-third Street, Philadelphia, Pa.
Mr. William Steell Jackson, Suite 1101, 112 South Sixteenth Street, Philadelphia, Pa.
Mr. Morris E. Leeds, 1025 Westview Street, Germantown, Phila., Pa.
Mr. Clifford J. Summers, 919 George Street, Chicago, Illinois.
Mr. Solomon M. Swaab, 7209 Wissahickon Avenue, Philadelphia, Pa.
Mr. Whitney Weinrich, Fairfax Hotel, Fifth Avenue and Craig Street, Pittsburgh, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

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U. S. National Advisory Committee for Aeronautics. Bibliography of Aeronautics, 1931. 1935.

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BOOK REVIEWS.

INTRODUCTION TO ELECTRIC TRANSIENTS, by Edwin B. Kurtz, E.E., Ph.D., and George F. Corcoran, M.S. 335 pages, illustrations. 15 × 23.5 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1935. Price $4.50.

For the study of any scientific subject, of first importance is the proper background. Such knowledge is the foundation upon which the structure of mastery of the subject is built. Books as tools for laying this foundation must contain all of the best qualities of material, and what is most essential, of methods of presentation. Introduction to Electric Transients contains all of these and more. It is divided into two parts. Section I treats on direct current transients beginning with elementary circuit concepts proceeding through mechanical analogies to the more complicated circuits with various arrangements of resistance, inductance and capacity assuming only self induction. Attention is then paid to circuit combinations in which mutual induction is an appreciable factor in governing the transient response.

Section II is devoted to alternating current transients. This section likewise proceeds from the elementary to the complex. The discussion avoids general mathematical predetermination of transient response in divided circuits with alternating voltage applied because, it is stated, elementary methods are not applicable except in simple cases. In dealing with variable circuit parameters, transients in alternating current motors and transient short circuit currents in alternators are considered.

The method of presentation employed is to consider each type of transient according to physical considerations to give a reasonably clear conception of the electrical situation. Mathematical analysis is next employed in which the results are derived in accordance with the laws of conventional mathematics, usually involving the use and solution of some form of differential equation. A mathematical appendix contains resumes of the differential equations of elementary circuit theory, Heaviside's operational calculus, the Graeffe method of solving algebraic equations, and exponential and hyperbolic functions.

All major discussions and analyses are accompanied by actual oscillograms. This makes for better appreciation of the equations representing circuits in which the parameters are known. There is remarkable agreement shown between the calculated curves and the photographic records.

That the book provides an excellent background for more advanced work in this field is an unquestionable statement. More than this, the presentation of the material is done in such a way that it proves most interesting and inspiring for further work.

R. H. OPPERMANN.

ELEMENTARY QUANTUM MECHANICS, by R. W. Gurney, M.A., Ph.D. 159 pages, illustrations, 14 × 22 cms. Cambridge, University Press, 1934. Price $2.35.

Progress in science has frequently brought to light serious oversights in fundamental theories that must be changed or that must be substituted by new theories. Thus, the prediction of the results of an atomic experiment on measure-

ment is often embodied in a distribution curve which expresses these results between certain limits. The conditions of the experiment cannot be made sufficiently precise to enable a prediction of a single definite value. The whole method is based on the assumption that any ideally precise measurement would lead to one unambiguous result and that by compounding these results the required curve was to be obtained. Quantum mechanics, however, is based on the revolutionary idea that the initial assumption is often wrong. It introduces the idea of purely theoretical curves or patterns of predicted results whose shape depends only on the nature of the universe and not at all on any particular apparatus or conditions of experiment.

With this introduction, after briefly touching on energy diagrams, the author leads us through treatments on the wave equation, the uncertainty principle and the movements of particles. Electrons in crystals are discussed together with conductors and insulators. Two chapters are devoted to the problems of valency and the properties of molecules. More than sixty diagrams illustrate graphically atomic and molecular problem treatment. A simple development of the Dirac perturbation theory is given showing how it handles excitation, dissociation, and other processes.

The book is thoroughly technical and is meant to enable the experimentalist to think in terms of wave mechanics. It should be extremely valuable to the physicist desiring to modernize his knowledge.

R. H. OPPERMANN.

THEORIE DER ELEKTRIZITÄT, von R. Becker. Band I, Einführung in die Maxwellsche Theorie der Elektrizität, 265 pages, illustrations, 15 × 23 cms. Leipzig und Berlin, B. G. Teubner, 1933. Price 14.50 marks.

In the year 1894 there appeared "Einführung in die Maxwellsche Theorie" by A. Föppl; ten years later came the revised second edition by Max Abraham as the first volume "Theorie der Elektrizität." Then for a whole generation the most used guide for physicists was "Abraham-Föppl" in the fundamentals of electricity. This book reached its seventh edition in the lifetime of Max Abraham.

The edition at hand is the tenth volume I and brings up to date the many changes that have occurred. The author a professor in der Technischen Hochschule Berlin, begins with a treatment on vectors from their definition to their complex use. This is classed as the first division of the book. The following divisions are in order devoted to; (1) the electric field including dielectrics and static electricity; (2) the magnetic field; (3) the Maxwell theory on energy and power including thermodynamics of field energy.

The text is concluded with twelve pages of problems and answers for exercises and an assemblage of formulæ and notes. A subject index is appended.

That a book that has stood so sturdily as a standard text is remarkable in itself. The make up and style of presentation are typically German—thorough, clear, and complete.

R. H. OPPERMANN.

AUTOMATIC PROTECTION OF A.C. CIRCUITS, by G. W. Stubbings, B.Sc. 293 pages, illustrations, 14 × 22 cms. Pittsburgh, Instruments Publishing Company, 1935. Price $5.00.

The supply of electrical energy has grown to such an extent that it is necessary now for practicing engineers to become specialists in one of the great many divi-

sions of the subject. When the art was in its early stages a knowledge of general theory was usually sufficient, but as it expanded each of the basic parts—generation, transmission, distribution, and utilization—became more and more complicated, so that today, in addition to a knowledge of general theory, the electric power engineer must cope with highly specialized problems that bear a relation to the whole. In consequence of this, text-books appear from time to time on these specialized subjects. This book meets the need for practical knowledge on its particular subject.

As in other electric power fields, the protection of the A.C. circuits has been and is going through many development stages, so that one must continually peruse literature on the subject in order to be posted. Beginners in the study of A.C. circuit protection as well as the experienced engineer will therefore appreciate the value of this book. From the fundamentals, the theory of protective transformers and their interconnection, and the theory of protective relays, the text proceeds to the dealing with modern protective circuits. A knowledge of alternating currents and vectorial representation is of course a prerequisite.

A glance through the book is sufficient to see its clarity of treatment and that there is throughout an intermingling of theoretical and practical knowledge. It not only tells why but how.

The protection of electrical machinery and of cables and transmission lines is discussed in detail from the reasons for the various faults on to the protective measures for each. A bibliography is appended of recent works and papers dealing with protective gear and apparatus. Of particular note is appendix II which contains a glossary of technical terms relating to protective gear. The subject index facilitates greatly the locating of information desired and adds much to the worth of the book as a reference work.

This book can be recommended to the student, the specialized technician and the general electric power engineer as a work of practical value.

R. H. OPPERMANN.

THEORY OF ALTERNATING CURRENT WAVE-FORMS, vol. 1, by Philip Kemp., Head of the School of Engineering at The Polytechnic, London. 218 pages, tables, illustrations, 14 × 22 cms. Pittsburgh, Instruments Publishing Company, 1935. Price $4.50.

The progress of the electrical engineering profession has advanced to the point when it is necessary for many of those who were trained in the "old school" to go back and review elementary theory and further add to their knowledge in order that a complete understanding may be had of modern conceptions. This is particularly true in relation to basic calculations in alternating currents. The usual assumption of the existence of a sine wave to begin with, is not sufficient in a greater number of instances. The whole subject of wave form has an added importance due, among other things, to the increasing use of the electron tube in the industry and the oscillograph.

This volume is an attempt to place before the reader those facts relating to non-sinusoidal waves which are necessary for a proper understanding of the subject, a general knowledge of alternating current theory being assumed. It devotes considerable attention to properties of complex waves and discusses, in this connection, power factor and superimposed D.C. and A.C. The effect of iron on wave

form is next taken up and contains very interesting information on permeability and hysteresis effects. Other circuit conditions that bear on the subject, harmonics in polyphase systems and the analysis of harmonics are all given thorough treatment. The subject is treated generally without reference to specific machines or types of apparatus but necessarily is very practicable and the knowledge obtained can readily be applied. The chapter on harmonic analysis is especially valuable. In it is discussed briefly and clearly Fourier's Series, Perry's Method which reduces the labor involved by employing a system of tabulation, the Thompson-Runge Method, and Kemp's Method.

A short bibliography is given after each subject for those wishing further to extend their knowledge. An index is appended.

The book is volume I of a series of monographs on electrical engineering, the object of which it is stated is to enable engineers, advanced students and others to obtain authoritative works on special and important subjects which are either ignored or inadequately dealt with in standard text books. It can be said without any reservation that this book excellently fulfills the purpose of presenting its subject with clarity and thoroughness.

R. H. OPPERMANN.

TELEPHONE THEORY AND PRACTICE, Vols. 2 and 3, Manual Switching and Substation Equipment; Automatic Switching and Auxiliary Equipment, by Kempster B. Miller, tables, illustrations, 15 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1933. Price $5.00 each.

These two volumes are Volumes II and III of a set of books on "Telephone Theory and Practice." They are naturally based on the elementary theory and with historical background furnished by Volume I, "Theory and Elements." Volume II, "Manual Switching and Substation Equipment" relates almost exclusively to the subscriber's station equipment and the central-office switchboards employed in manually operated exchanges. In it there is described talking and signalling apparatus, subscriber's sets and individual and party lines. This is classed as substation equipment. Under the heading of manual switchboards, there are treatments on non-multiple magneto switchboards, current supply in common battery exchanges, and multiple switchboards.

Illustrations and diagrams are used profusely to bring out the descriptions. The method in which each subject is approached and presented is attractive and makes it easy to understand. In various parts of the book a bit of history is included to show in a brief space the developments leading up to the present equipment or part treated.

"Automatic Switching and Auxiliary Equipment," Volume III of the series, treats principally on all four types of machine switching systems now in use They are the step-by-step, panel, rotary and all relay systems. Under auxiliary equipment there are chapters devoted to power plants, including treatments on the kinds of batteries and rectifiers, their operation, connections and care; protective apparatus dealing with lightning protection, high tension power lines and the equipment used; distributing frames, the various kinds and their functions; branch private exchanges and toll switching.

This book, similar to Volume II, is written in a very clear manner. It shows by illustrations and descriptive matter the practical facts on equipment

and circuits. Everyone interested in the design, construction, installation and operation of the modern telephone equipment at subscribers stations should not fail to become familiar with these books. They give a practical detailed treatment in an attractive and simple manner.

R. H. OPPERMANN.

ÉLECTROLYTES. By Hans Falkenhagen, Professor, University of Cologne. Translated from the Original German into French by G. Mano. Preface by P. Debye. 358 pages, 15.6 × 23.5 cms. Paris, Librairie Félix Alcan, 1934. Price 60 Francs.

In this monograph Falkenhagen helps greatly to organize the vast accumulation of data and theory—irreverent individuals might allude to the same as fact and fancy—in the enormously difficult field of electrolytes. Levity aside, however, this subject has claimed the serious efforts of foremost scientists for over 50 years. Sound progress has been slow but is being made although still one can only with difficulty extend the theory to embrace "concentrated solutions"—not so very concentrated at that. The field of colloidal electrolytes being only in its first stages of development intentionally is not treated.

Organization of the book is as follows: First, definitions, the thermodynamic laws of ideal dilute solutions, Arrhenius' electrolytic dissociation theory, the contributions of Ostwald and Nernst. Next follow the Lewis activity concepts and experimental methods. Chapter V discusses anomalies in conductivity (failure of Ostwald dilution law, non-aqueous solutions, Wien effect and variation of conductivity with frequency). Disposal of earlier chemical and physical theories of the anomalies sets the stage for extended consideration of the Debye-Milner theory of strong electrolytes (in dilute solutions). A short chapter on viscosity of strong electrolytes from the ionic atmosphere point of view precedes the development of theories for more concentrated solutions (Debye and Hückel, Bjerrum, and Grownwall, LaMer and Sandved). The remainder of the volume deals with determination of true degree of dissociation. The matter of reaction kinetics is not taken up, dependence being placed on other works. It is unfortunate that such an integral part of the subject is not included, at least in abstract.

The French edition has been revised from the German text of 1932 to the extent necessary to bring it up to July, 1934. The close relationships existing between the author and Debye, Wien, Hückel, Brönsted, Bjerrum and others as well as his own contributions in the field endow the work with a considerable degree of authority. The index is not very satisfactory but we can approve of the practice of setting names in the text in heavy type. Extensive references are given.

A German-English translation by R. P. Bell is also available.

LESLIE R. BACON.

LEITFADEN DER ELEKTROTECHNIK, Herausgegeben von Dr.-Ing. G. Bolz, Dr.-Ing. F. Moeller, Dipl.-Ing. Th. Werr, Band I, Teil 1 und 2, Grundlagen des Gleich- und Wechselstromes, von F. Moeller and G. Bolz. 102 pages, diagrams, 16.5 × 24 cms. Leipzig und Berlin, B. G. Teubner, 1933. Price 9.60 RM.

This Volume I of a work on electrical engineering treats with the fundamentals of electricity and magnetism with direct relation to practical application primarily.

Its intent is to prepare the general engineer for the study of Volume II on direct and alternating current machinery. The many different applications of electrical engineering in industry require not only the specialist but practically all engineers to include in their knowledge the fundamentals of electrical engineering. The material in this work is chosen and presented with this idea in mind.

The book is divided into two main parts. The first deals with fundamentals of electric circuits, electrical energy, production of heat and electro-chemical production of electric current. The magnetic field is treated in a very interesting manner. The field in air and in iron is discussed separately, preceding discussions on production of electric potentials by rotating principles and transformers. In conclusion there is given somewhat detailed calculations on the magnetic circuit and the electric field.

The second part is devoted to alternating current circuits, vectorial representations of alternating currents, the sine wave, effects of capacity and induction and effects of iron in the circuit. Polyphase alternating currents are treated separately.

The book is admirable for its clarity and compactness. While it gives a scientifically accurate conception, the topics are so chosen as to eliminate all but what is absolutely necessary for practical knowledge of theory. Only in a few cases does it utilize the calculus. From preparation by the use of this book one should be able to persue special studies on the more advanced electron and field theory without difficulty.

The book can be recommended to all scientifically minded people requiring a fundamental knowledge in electrical engineering.

R. H. OPPERMANN.

THE ELEMENTS OF MOTOR VEHICLE DESIGN, A TEXT-BOOK FOR STUDENTS AND DRAUGHTSMEN, by C. T. B. Donkin, A. C. G. I. 284 pages, illustrations, tables, 14 × 22 cms. Oxford University Press. London, Humphrey Milford, 1935. Price $4.25.

A rather light and very interesting treatment of those things about a motor car that apply to every make of car. These are the fundamental laws and their applications; such as may arise in the design or repair of motor vehicles.

The book may be divided roughly into three parts; the first dealing with the power plant having to do with the thermodynamics of the engine, horse power and efficiency, tractive effort, carburation and ignition, and valve timing; the second part treating on the transmission of the power including clutches, gearing, propeller shafts, etc.; the third part being devoted to the steering apparatus, brakes, frames and springs.

The approach throughout the book is based on the underlying desire to satisfy the practical needs of the reader. This is best illustrated at the very beginning wherein the use and construction of motor vehicles is considered, a very elementary discussion, and followed by a chapter on the materials of construction which gives a brief space on the properties of the principal materials, because it deals with the practical aspects of theory, eliminating highly specialized aspects, the book is not an advanced treatise. Workers in the drafting room or factory of the manufacturing plant or in the repair shop should be especially interested. Only an elementary knowledge of mechanics and practical mathematics (exclusive of the calculus) is required.

The drawings and illustrations contained throughout the book assist greatly in obtaining a clear understanding. Examples in the solution of various problems merits special mention as they provide a workable knowledge of the hows and whys treated on earlier. This also applies to problems given at the end of chapters, the answers to which can be found in the back of the book. These things, together with the attractive style of writing and the clever blending of the various subjects together give the book an outstanding value for home study.

R. H. OPPERMANN.

ELEMENTE DER ELEMENTAREN MECHANIK, von K. H. Grossmann, I teil. 99 pages, diagrams, 15 × 21 cms. Zurich, Karl H. Grossmann, 1934. Price 3 Francs Swiss.

As the title implies, this is part I of a work on mechanics. It is an admirable attempt to present important mathematical features in a handy and compact little volume. At the beginning the text goes directly into vectorial representation as applied to subjects in mechanics and it dwells throughout on the use of vectors for the solution of problems in mechanics. The author has very carefully selected only such matter as is best illustrative of each of his well planned assertions and he has very expertly woven the subjects together so that as a result there is a comprehensive mathematical treatise. The student in mechanics and the practical mathematician should find in this book the necessary fundamentals which can be readily applied to the solution of problems in the field and which can be used as a basis for more advanced study.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 496, General Theory of Aerodynamic Instability and the Mechanism of Flutter, by Theodore Theodorsen, 23 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

The aerodynamic forces on an oscillating airfoil or airfoil-aileron combination of three independent degrees of freedom have been determined. The problem resolves itself into the solution of certain definite integrals, which have been identified as Bessel functions of the first and second kind and of zero and first order. The theory, being based on potential flow and the Kutta condition, is fundamentally equivalent to the conventional wing-section theory relating to the steady case.

The air forces being known, the mechanism of aerodynamic instability has been analyzed in detail. An exact solution, involving potential flow and the adoption of the Kutta condition, has been arrived at. The solution is of a simple form and is expressed by means of an auxiliary parameter k. The mathematical treatment also provides a convenient cyclic arrangement permitting a uniform treatment of all subcases of two degrees of freedom. The flutter velocity, defined as the air velocity at which flutter starts, and which is treated as the unknown quantity, is determined as a function of a certain ratio of the frequencies in the separate degrees of freedom for any magnitudes and combinations of the airfoil-aileron parameters.

For those interested solely or particularly in the numerical solutions, Appendix I has been prepared. The routine procedure in solving numerical examples is put

down detached from the theoretical background of the paper. It first is necessary to determine a certain number of constants pertaining to the case, then to perform a few routine calculations as indicated. The result is readily obtained in the form of a plot of flutter velocity against frequency for any values of the other parameters chosen. The numerical work of calculating the constants is simplified by referring to a number of tables, which are included in Appendix I. A number of illustrative examples and experimental results are given in Appendix II.

Report No. 513, Experimental Investigation of the Robinson-Type Cup Anemometer, by M. J. Brevoort and U. T. Joyner. 24 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

An investigation on the Robinson-type cup anemometer has been completed by the National Advisory Committee for Aeronautics. This investigation covered force measurements on individual cups, as well as static and dynamic torque measurements and calibrations on complete cup wheels. In the tests on individual cups 5 cup forms were used and in the measurements on complete cup wheels 4 cup wheels with 3 arm lengths for each cup wheel were tested. All the results are presented in graphical form.

Report No. 524, A Turbulence Indicator Utilizing the Diffusion of Heat, by G. B. Schubauer. 5 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price five cents.

In coöperation with the National Advisory Committee for Aeronautics, the National Bureau of Standards for several years has been studying methods of determining the turbulence in wind tunnels, especially by the "hot-wire" method and the sphere method. This paper describes a third method.

The effect of turbulence upon the diffusion of heat from a small electrically heated wire in an air stream was investigated. The turbulence of the stream was introduced by a series of geometrically similar screens placed one at a time across the upstream section of the tunnel. With the wire set at various distances from the screens, curves of temperature distribution were obtained by traversing the heated wake at a distance of 2 inches behind the wire with a small thermocouple. A single relation was found to exist between the width of the wake at half maximum and distance in screen wire diameters from the several screens. The correlation of width at half maximum with percentage turbulence, as measured by the "hot-wire" method, could be represented approximately by a single curve.

R.

DIE ELEKTRISCHE WÄRMBEHANDLUNG IN DER INDUSTRIE, von E. Fr. Russ. 259 pages, illustrations, tables, 16.5 × 24 cms. München und Berlin, R. Oldenbourg, 1933. Price 14 marks.

This book is a practical work on electrical methods for industrial heat treatment. It is devoted especially to the design and construction of the various types of electrically heated ovens and their electrical control and other apparatus. First there is a general treatment of the subject sufficient for the reader to estimate the possibilities in certain industries. This is followed by explanations on the field of utilization including the heat treatment of steel, iron, and other metals and industrial products. In the last and largest part of the book there is a rather

complete discussion on the design of electric ovens. Each subject is discussed separately. Heating units and their arrangement for different purposes, refractory and insulation material, temperature regulation, etc., all are given consideration, from the smallest to the largest oven and for ovens for a variety of purposes.

The book is profusely illustrated and contains a very handy index in the back. Only the necessary theory to make clear the present condition of electric heat treatment is included in the book. It is a handy and useful little volume to those whose interests lie in this direction.

R. H. OPPERMANN.

RESEARCH, THE PATHFINDER OF SCIENCE AND INDUSTRY, by T. A. Boyd, 319 pages, 13.5 × 20.5 cms. New York and London, D. Appleton-Century Company, Inc. 1935. Price $2.50.

A unique presentation in a fascinating way of the modern term "Research." Of recent years this term has taken on added significance, replacing the discoveries and explorations of the past, and now being applicable to every field of human endeavor. The cook who experiments to develop new recipes, the mathematician who contributes to the progress of science, the man who stands on the sidewalk counting the passers-by in order that a chain store may find the best location are all research workers in the modern sense. It is in this realm that can be found the present day adventure of the explorer. The scenes have been shifted from extending the frontiers of "that which is" to the frontiers of "that which can be."

In an easily understandable style the author sets out with the definition of what research is and the distinction between pure and applied research. The methods of invention, the organization and financing of research, and the planning of laboratories are all taken up. One of the most interesting parts of the book is that devoted to the research worker himself. In it is discussed the qualifications, training and recruiting of the workers. The traits of the individual such as curiosity, imagination, enthusiasm, patience and others all combine to make up the modern explorer. In a further section of the book there is analyzed the spectacular achievements of organized industrial research in the discovery and improvement of products and processes. In this, of timely interest is the chapter devoted to industries destroyed. Here is illustrated not only industries which became obsolete due to the march of progress but industries which saved themselves from obsolescence by turning to the research laboratory.

The book serves many useful purposes, chief among which are the clarification of the subject in the mind of the man considering a career in research, a good explanation of what research is, and general information for those intending to establish departments in industry.

R. H. OPPERMANN.

THE BOOK OF STAINLESS STEELS, CORROSION RESISTING AND HEAT RESISTING CHROMIUM ALLOYS, edited by Ernest E. Thum, second edition. 787 pages, illustrations, tables, 15.5 × 24 cms. Cleveland, American Socitey for Metals, 1935. Price $4.50.

Much of the present day standard of civilized life is due to the pioneers in various branches of science who in one way or another gave themselves unsparingly to the development of new knowledge. One of the best illustrations of this is in

the steel industry where iron and its common alloy known as steel, has been transmuted into a noble metal, not by alchemy, but by modern metallurgical science. We now have alloys of iron which do not rust at the seashore, which do not dissolve in hot, strong acid, or do not scale at 2000° F. All this has come about in recent years and the materials that we now have by no means constitute a limit. This development has been accomplished by the cooperation and mutual understanding of the requirements and problems of the steel maker and user, and lastly and certainly of equal importance, the energetic men in many progressive companies who have had the courage to back their faith in the new alloys with real money.

The book gives an excellent account of such cooperation. It presents a picture of the science and technology of the subject, the result of the joint effort of some seventy-five men, each an expert in some branch of industry and technology. Because the book consists of a series of individual contributions sponsored by individual authorities it is quite impossible to do fairness to each contributor in the space here allotted for review. The papers are well chosen and are written in a style which should prove interesting and instructive reading. The book as a whole is divided into six parts. Starting with Part I the reader is introduced to a brief history and treatment on general requirements of alloyed steels and how they are met. Following this one is taken through parts devoted to production and fabrication including the problems of melting and casting, rolling mill practice, finishing and fabricating operations, welding and duplex materials; properties of the typical alloys devoted, among others, to the subjects of low and high carbon stainless steels, chromium ferrites, higher alloys of chromium-nickel-iron and other high chromium alloys; specialized tests; requirements of the consuming industries; indexes giving trade names and list of manufacturers.

The editor states that he has grouped all the high chromium heat and corrosion resisting steels under the term "Stainless Steels." Few of them are stainless but common usage has broadened the term to include all steely colored metals that do not tarnish readily. Trade names in the body of the book have been generally avoided except for certain ones established early and monopolized by patent restrictions.

Because of its completeness in the coverage of the subject, its clarity with respect to details, and the care in which it has been gotten together the book is a remarkable contribution to the literature. It is truly an instrument for practical knowledge.

R. H. OPPERMANN.

W. C. RÖNTGEN BRIEFE AN L. ZEHNDER, MIT DEN BEITRÄGEN GESCHICHTE SEINER ENTDECKUNG DER RÖNTGENSTRAHLEN UND RÖNTGENS EINSTELLUNG ZUR RENAISSANCE DER KLASSISCHEN PHYSIK, von Dr. Ludwig Zehnder, a. o. Professor für Physik an der Universität Basel. 198 pages, illustrations, 16 × 23 cms. Zurich, Rascher & Cie., 1935.

This very interesting publication is in commemoration of the ninetieth birthday of the great Röntgen and of the fortieth year of his great discovery. It consists of letters to and from the author and Röntgen, which are of most interest in connection with his discovery. Here are his own words. This should throw much light with regard to the various legends that have been published about the

method of his discovery. The author states that only a few of the letters during this period are not included because they have little bearing on the subject. None have been excluded that have reflections on the author. The originals are deposited in the library at Zurich. Needless to say the letters and photographs contribute much toward knowledge of activities of a great man. The publication is a true narrative of the discovery of the Röntgen ray.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

The Elements of Motor Vehicle Design, a text-book for students and draughtsmen, by C. T. B. Donkin. 289 pages, illustrations, tables, 14 × 22 cms. London, Humphrey Milford, 1935. Price $4.25.

Pression Solaire et Atomes la Circulation de l'Énergie, par le Dr. Georges Froin. 250 pages, tables, 16 × 24 cms. Paris, Librarie Louis Arnette, 1935.

Les Logarithmes et les Puissances en Partant de l'Hyperbole, par Henri Tripier. 50 pages, 14 × 23 cms. Paris, Librairie Vuibert, 1934.

The Frontiers of Psychology, by William McDougall, 235 pages, 13 × 20 cms. New York, D. Appleton-Century Co., Inc. Cambridge, University Press. Price $2.00.

The Book of Stainless Steels, Corrosion Resisting and Heat Resisting Chromium Alloys, edited by Ernest E. Thum, second edition. 787 pages, tables, illustrations, 15.5 × 23.5 cms. Cleveland, American Society for Metals, 1935.

Research, The Pathfinder of Science and Industry, by T. A. Boyd, 319 pages, 14 × 20.5 cms. New York and London, D. Appleton-Century Company, 1935. Price $2.50.

Canada Department of Mines, Petroleum Fuels in Canada, Deliveries for Consumption, Calendar Year 1933, prepared by John M. Casey. 12 pages, tables, 16.5 × 24.5 cms. Ottawa, King's Printer, 1935. Price ten cents.

U. S. Coast and Geodetic Survey, Special Publication No. 129, Geodetic Level and Rod, by D. L. Parkhurst, 14 pages, illustrations, 15 × 23 cms. Washington, Government Printing Office, 1935. Price five cents.

Bell Telephone Laboratories, Monographs: B–846, Shot Effect and Thermal Agitation in a Space Charge Limited Current, by G. L. Pearson, 8 pages, diagrams. B–847, Chemical Studies of Wood Preservation, by Robert R. Williams, 48 pages, tables, illustrations. B–848, Note on Vacuum Tube Electronics at Ultra-High Frequencies, by F. B. Llewellyn, 16 pages, illustrations. B–849, Hard Rubber (Ebonite), by A. R. Kemp and F. S. Malm, 15 pages, illustrations, tables. B–850, A High Speed Level Recorder for Acoustic Measurements, by E. C. Wente, E. H. Bedell, and K. D. Swartzel, Jr., 16 pages, illustrations. B–851, Reverberation Time and Absorption Measurements, by E. H. Bedell and K. D. Swartzel, Jr., 7 pages, illustrations. B–852, Simple Theory of the Three-Electrode Vacuum Tube, by H. A. Pidgeon, 42 pages, diagrams. B–853, The Ionizing Effects of Meteors, by A. M. Skellett, 18 pages, illustrations, tables. 8 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1935.

U. S. National Bureau of Standards, Circular C406, Standard Time Throughout the World, 24 pages, tables, plates, 15 × 23 cms. Washington, Government Printing Office, 1935. Price five cents.

National Advisory Committee for Aeronautics, Technical Notes, No. 523, Strength Tests of Thin-Walled Duralumin Cylinders in Combined Transverse Shear and Bending, by Eugene E. Lundquist, 18 pages, tables, illustrations. No. 524, Wind-Tunnel Tests of a Wing with a Trailing-Edge Auxiliary Airfoil Used as a Flap, by Richard W. Noyes, 10 pages, tables, illustrations. No. 525, The Aerodynamic Drag of Flying-Boat Hull Models as Measured in the N. A. C. A. 20-Foot Wind Tunnel—I, by Edwin P. Hartman, 9 pages, tables, diagrams. No. 526, Spinning Characteristics of Wings, II, Rectangular Clark Y Biplane Cellule: 25 Per Cent. Stagger; 0° Decalage; Gap/Chord 1.0 by M. J. Bamber, 13 pages, diagrams. 4 pamphlets, 20 × 26.5 cms. Washington, Committee, 1935.

CURRENT TOPICS.

Low-Temperature Portland Cement.—A very good description of the low-temperature cement being used for constructing Boulder Dam is furnished by G. R. ROBERTSON in the March, 1935 *Industrial and Engineering Chemistry*. It is generally known that concrete gives out heat during its setting up period. With concrete structures of ordinary size, the heat produced by hydration, escapes freely and causes no concern. However, with so great a mass as that of Boulder dam, which is essentially a monolith weighing about 7 million tons, normal temperature could not be attained in its depths much before the passage of 200 years. Such a condition would be intolerable, for the interior would be at a very high temperature while the exterior portions will have already radiated their heat and become fully contracted. No concrete structure embodying such a simultaneous combination of expanded and contracted sections could endure for long. Cracks would occur throughout and the mass would never develop the maximum strength intended.

Obviously, care was necessary in order that the concrete in Boulder Dam should not become overheated and require a correspondingly longer time in which to cool. One very good precaution was that of using a cement which would set with the development of much less heat. Fortunately this was easy to do since here was one instance where research had kept pace and even slightly surpassed the demands of the industry. Thus, it is generally agreed today that Portland cement is composed of four major constituents: (1) Tetracalcium alumino ferrite (C_4AF) $-4CaO.Al_2O_3.Fe_2O_3$; (2) Tricalcium aluminate (C_3A) $-3CaO.Al_2O_3$; (3) Dicalcium silicate (C_2S) $-2CaO.SiO_2$; and (4) Tricalcium silicate (C_3S) $-3CaO.SiO_2$. Using this basis for characterizing two well-known types of cement we find the following differences:

Component.	Ordinary Cement.	Boulder Dam Cement.
C_4AF	8	14
C_3A	12	6
C_2S	25	54
C_3S	65	18

Further research has shown that C_2S emits the smallest amount of heat within a setting-up period of 180 days. C_4AF will give out about $1\frac{1}{2}$ times as much as C_2S; C_3S emits about $2\frac{1}{2}$ times as much

while the heat developed by an equivalent weight of C_3A is four times as great as the C_2S. Actual tests indicate that the Boulder Dam cement will develop only 70 per cent. as much heat as will ordinary cement.

Even a 30 to 40 per cent. reduction in the heat developed by the cement was not sufficient to eliminate the difficulties attendant to a mass of the size here under discussion. Therefore, about 300 miles of light-weight, one-inch pipe have been embedded in the concrete and through these pipes refrigerated water or brine is passed. Only during the winter did the setting of low-heat cement prove to be somewhat too slow, so that the plan was adopted of mixing a small portion of ordinary cement with the standard concrete batches.

C.

Beneficial Molds.—It must be admitted that the chemists in the U. S. Department of Agriculture know their molds. Just recently H. T. HERRICK, R. HELLBACH and O. E. MAY reported a cheaper and faster method for making calcium gluconate by a more efficient use of molds as fermentation agents. Six years ago, Herrick and May discovered a mold that produces gluconic acid from glucose or corn sugar. This acid is important in the manufacture of calcium gluconate, which until that time sold for about $150 a pound. With introduction of the new process, this rare chemical, commonly prescribed for expectant mothers and others who need calcium, probably can be made and sold for less than 50 cents a pound.

Because molds must have air, the chemists grew them on the surface of shallow pans in the laboratory. This technique is not readily adaptable to large scale commercial production so a way was sought to make the molds grow beneath the surface as do yeasts in the manufacture of alcohol. The result is a rotating drum equipped with paddles on the inside of the drum—somewhat like a rotary churn. Air is forced into this drum under pressure through one end, and is removed through the other end.

Tests over several months show three important advantages of the new method for making gluconic acid. With the rotating drum, 10 pounds of sugar yields 8 pounds of gluconic acid, compared with 5½ pounds when pans are used. The time required is only one-fifth of that formerly needed. Because of its application in making gluconic acid, the new rotating drum method has promising possibilities for making other organic compounds of industrial importance

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While on the subject mention should be made of the Bureau chemists' success in harnessing another mold, a species of *Rhizopus*

and a relative of the common bread mold. When properly fed and cared for this *Rhizopus* produces sarcolactic acid, a component part of ordinary lactic acid which is found in milk.

Sarcolactic acid derives its name from the fact that it was originally prepared in 1908 from animal flesh. It is found in small quantities in the human body, and plays an important part in human metabolism—the process by which the body converts food into fuel and energy. Heretofore the only lactic acid produced industrially has been the inactive form, which is manufactured by the bacterial fermentation of starch. The sarcolactic derivative, also known as dextrolactic acid, had been made only in the laboratory and up to the present time has usually contained impurities.

C.

A College Course on Streamlining.—A course on the basic aerodynamic and dynamic principles of streamlined trains and other high speed railroad equipment will be given this fall at the Daniel Guggenheim School of Aeronautics in the College of Engineering at New York University. One of the chief reasons for giving the course was that a number of graduates from the aeronautical school had found employment as specialists in the design and construction of high speed trains and locomotives.

The laboratory of the School has developed an entirely new form of apparatus for the wind tunnel testing of trains and automobiles. This was designed on a plan first attempted unsuccessfully twenty years ago by Alexandre Gustave Eiffel, French engineer and builder of the Eiffel Tower. It is in the form of a continuous belt which is placed under the model to be tested and runs at the same speed as the airflow in the wind tunnel. During tests the train is held stationary and the air and "tracks" move at speeds which reproduce conditions up to 70 miles an hour.

C.

Fast Colors.—(U. S. D. A. Clip Sheet No. 875.) The Federal Bureau of Home Economics cautions the purchaser of fabrics that there is more than one kind of color fastness. Thus, the percale or gingham that doesn't run in the tub may fade in streaks when out in the sun. The dress that keeps its color through many launderings may be badly affected by perspiration. For this reason, careful reading of garment labels before purchasing is recommended by the Bureau. A label that says color fast to sun and washing" leaves one in no doubt as to what the article will stand in everyday use. An even better label observed recently read: "XYZ colors are fast to soap and boiling, to sun and weather, to perspiration and uric acid, fast to everything they encounter as wash fabrics."

C.

How Wet Wood Should Be.—(U. S. D. A. Clip Sheet No. 874.) The Forest Service Division reminds us that lumber going into building use should be dried no more and no less than enough to match the average moisture conditions which will surround it in service. Shrunken woodwork and flooring form frequent examples of instances where the wood is not dry enough to be installed in heated buildings. Now and then the reverse occurs, for it is quite possible to have wood too thoroughly dried when placed in service. A clear example of this was observed recently when ceiling boards in the cooling room of a meat-packing plant swelled badly and bucked into troughs and ridges. Relative humidity was very high at all times and the wood, installed at a moisture content of probably 12 per cent. and laid tight, picked up moisture to a total of 22 per cent. The recommendation of the Forest Products Laboratory in all cases is to find out how dry or how damp the service conditions will be, and then to obtain lumber properly seasoned to fit the conditions. C.

Warm Baths for Plants.—(U. S. D. A. Clip Sheet No. 872.) Entomologists of the U. S. Department of Agriculture have found that hot water or vapor heat treatments for greenhouse plants not only kill the destructive mites but also stimulate plant growth in many cases. Great care is necessary in giving plants their hot-water dips since too much heat is as fatal to the plants as to the pests. Twenty minute dips at 108° F. will destroy the mites without injury to such extremely delicate plants as the cyclamen, chrysanthemum, geranium, lantana, fuchsia and begonia. Immediately following treatment all excess water should be drained away from potted plants to avoid root injury.

In another series of tests the root clumps of spirea were treated with vapor heat at a temperature of 110° F. for 1 hour. This not only killed the larvæ of a destructive weevil but also stimulated growth, so that the flowers bloomed from 40 to 60 days earlier than usual. C.

New Fool-Proof Explosive.—(*I. & E. C.*, News Edition, Vol. 13, p. 93.) A new super-safe blasting material for use in quarries and stripping operations was announced at a Technical Section Convention of the duPont Company Explosives Department held in Wilmington, Del., on January 22. This new product cannot be detonated by the strongest commercial blasting cap, by impact, by flame, nor by shooting a rifle bullet into it. It is non-freezing and non-headache producing. In actual use it is exploded by means of a large diameter cartridge of dynamite.

M.I.T. Analyzer Interprets Weather in Terms of Comfort.—(*Heating and Ventilating*, Vol. 32, no. 4.) ATHELSTAN F. SPILHAUS has developed at the Massachusetts Institute of Technology an instrument which analyzes temperature and relative humidity and in a single reading indicates prevailing weather conditions in terms of personal comfort. The device combines a bimetal thermometer and a hair hygrometer. It does not make weather forecasts but the indications of prevailing conditions are made in terms of scorching, muggy, damp, etc., from day to day. Both the dial of the instrument and the needle pointer move in the process of giving one reading. The dial, rising and falling, registers temperature, while the indicator finger moves left or right in registering humidity. On the face of the dial is a series of curved lines, like those of latitude and longitude on a globe map. The outside circle shows temperature degrees. The lateral curves indicate at different points on the dial, in connection with temperature, the various popular terms of weather phases. The instrument is expected to be of value in indicating comfort zones of heat and moisture in air conditioned buildings, and in other ways such as warning air pilots of dangerous conditions of temperature and humidity in which ice begins to form on airplane wings.

R. H. O.

An Artificial Cliff.—(*Eng. News Rec.*, Mar. 28, 1935.) The most interesting feature of the new 35 acre zoölogical park at Vincennes, France, is an artificial cliff of reinforced concrete rising to a height of 220 ft. and occupying nearly one acre of ground. This "Great Cliff" described by L. FAUCHEUR AND H. DURNERIN in *Travaux* of June 1934, shelters the lions and the tigers as well as the birds of prey and offers the mountain goats and the wild sheep a fair imitation of their natural habitats. Furthermore, it serves as an observation tower, made accessible to the public by a centrally located elevator and winding staircase leading to a platform 213 ft. above the ground, and it also houses the standby waterworks of the zoo, comprising two reservoirs. In designing this unusual structure wind pressure was neglected up to a height of 50 ft. Interior framing was designed as a simple rectangular system of reinforced-concrete posts and beams without any encumbering diagonal bracing, divided into twelve stories, 16 to 20 ft. high. The exterior shell was moulded by successive depositions of cement and mortar coatings on a fine mesh netting of thick wire stretched on the concrete framework of the cliff in accordance with a 1:50 architectural model.

R. H. O.

Illumination Experts Refuted.—(*Science Service.*) It would appear from a survey of research studies by DR. MILES A. TINKER, of the University of Minnesota, that it is not necessary to buy electric light bulbs of extremely high wattage in the fear that use of less powerful lights will ruin the eyesight of members of the household. Reading by lights of lesser intensity does not cause eyestrain unless the eyes are abnormal or the print illegible. In fact, the contrary may be true. Lights of the extremely high intensities often recommended as healthful and necessary may cause discomfort by producing glare.

According to Dr. Tinker there is no valid evidence to support the suggestions that the normal eye needs from 25 to several hundred foot-candles of artificial illumination for easy and efficient reading of legible print. His recommendations as applied to the normal eye are:

1. For direct lighting with poor distribution, 3 to 5 foot-candles.
2. For combination of direct and semi-indirect illumination frequently found in homes, 5 to 10 foot-candles.
3. For the better degrees of light distribution found in some homes and offices, 10 to 15 foot-candles.

C.

Spent Refinery Clays Employed in Plastic Waterproof Cement.—Wastes from one industry often can be profitably used in another industry. According to A. R. Chandler (*National Petroleum News*, April 10, 1935) many oil refineries that have the proper kind of spent clay available which at the present time probably causes considerable concern regarding its disposal, may dispose of much of it profitably to the cement industry if a broad use of the Evans process is made.

The Evans process for the manufacture of plastic waterproof cement (U. S. Pat. 1,755,638, Canadian Pat. 330,109) uses spent clay, or fuller's earth, obtained from oil refineries. It has been found that the best spent clay to use is that which is obtained from the contacting or percolation methods used in the manufacture of lubricating oils. Spent clay therefore is a mixture of activated clay, asphaltic, resinous and polymerized bodies with no free oil. It should contain between 20 and 40 per cent. petroleum products.

The spent clay is usually added during the manufacture of cement into the ball or tube mill when the clinker is being ground. If it contains 25 per cent. oil then approximately 3 per cent. by weight of the spent clay should be added to the clinker being ground. The resultant product is a plastic waterproof cement of excellent quality as to strength.

R. H. O.

Pennsylvania Builds Tunnel at Baltimore.—(*Railway Age*, Vol. 98, no. 15.) In 1873 a five-ring brick arch tunnel was built which until the present time was used for railroad freight and passenger traffic moving north and south along the eastern seaboard. With the electrification of the Pennsylvania Railroad, a new tunnel was necessary because the old one was not only too small in section to provide clearances for double track electrified operation, but was in need of considerable repair. The new tunnel, 3,403 ft. long, lies 51 ft. to the south of the old one, and is for double track operation. Arrangements are made for possible future single track electrified operation through the old tunnel.

The new tunnel, which is semi-circular in section above a point 6½ ft. above the base of the rail, was built in three sections; a cut-and-cover section 946 ft. long at the west end, provided with a concrete arch; the tunnel itself, a shield-driven section 2,085 ft. long, lined with cast iron; and another cut-and-cover section at the east end, 295 ft. long with concrete arch. The entire length is of the same inside cross section with a clear width of 33 ft. at the lowest point of the arch and a clear height of 22 ft. 3 in. above top of rail.

The cut and cover method of construction was employed at the ends of the tunnel because, at the west end, the cut was fully one-third rock and because of the relatively shallow cover, but the shield method of construction was considered safer for the main portion of the tunnel, where the over-burden ranged from 20 to 30 ft. in depth. The material penetrated consisted generally of glacial drift overlying hard gneiss, but separated therefrom by a layer of decomposed gneiss. There was no regular water plane.

The tunnel project was begun on July 17, 1933. By September 17, 1934, only 20 days after holing through, the permanent tracks were laid and ballasted throughout, the electric catenaries were erected, and an inspection train was moved through the tunnel.

R. H. O.

The Edgar Allen-Buell Flue Gas Dust Separating Plant.—(*Eng.*, Mar. 22, 1935.) This separator utilizes the principle of centrifugal force in a distinctly different manner from what has hitherto been customary. A fundamental part of the new design is the utilization of the double eddy current existing whenever a stream of gas or air flows along a curved path. The conventional centrifugal dust separator is improved by an external by-pass arrangement. The upper part of the centrifugal drum is the site of an eddy revolving in a clockwise direction in a plane at right angles to the path of the gases around the drum. In the lower part of the drum and the conical hopper is a second eddy revolving in a counter clockwise

direction. The gases enter through an opening in the drum arranged tangentially and extending from the bottom to a point about a quarter of the depth from the top; they escape through a central pipe. The effect of the double eddy has been shown to be sufficiently marked to neutralize completely and even overcome the centrifugal action due to the swirl of the gases in the horizontal plane in the positions in which it is directly opposed to this action. The result is that the dust accumulates at the top until its mass is sufficient to overcome the pressure of the upward current. When this occurs the dust slides down into the hopper where the bottom current assists its descent. The dust may be removed from the top of the drum by means of the external by-pass. The second feature of this separator is an opening with deflecting vanes in the prolonged outlet pipe or chimney at a point where centrifugal action and eddy currents are carrying the dust away from it, so that any gas passing through it will come from the area which is most free from dust. A third feature is that in the normal arrangement there are two drums, viz., a primary drum and a secondary drum, the latter being integral with the dust collecting hopper. The overall efficiency of the plant was shown by tests to be 96.1 per cent. For dust of 60 microns diameter and over the efficiency was 99.5 per cent., and for dust of 40 microns and over it was 99.1 per cent.

R. H. O.

Rayon from Sugar Cane.—Working in the laboratories of the Bureau of Chemistry and Soils, D. F. J. LYNCH has perfected a process for the manufacture of alpha cellulose from sugarcane bagasse. Bagasse—the refuse from sugarcane mills—offers interesting possibilities since there is no problem of collecting this raw material at the factory as there would be in the case of corn stalks. It has already been accumulated in great quantities at the sugar mills and in the past has been useful mainly as fuel. In recent years wall boards have been made from bagasse, but this outlet is limited.

The process uses dilute nitric acid as the pulping agent. This acid is now relatively cheap because of the availability of large quantities of liquid ammonia. The nitric acid process as developed gives higher yields and purer cellulose from bagasse than those obtained from any of the standard commercial pulping methods.

This summer, the nitric acid process is to be tried out in Hawaii on a semi-commercial scale. There is every promise that a high grade cellulose approaching that made from cotton linters will be the result. Should the tests prove satisfactory, additional plants undoubtedly will be built in Louisiana and Puerto Rico.

C.

Demand Totalization.—One of the recent marvels of electric power engineering is telemetering by which it is possible to obtain indications of electrical measurements from a distance. It is with much interest that we read the article by A. R. RUTTER and PAUL MAC GAHAN in the *Electric Journal*, April 1935. It describes an instrument which registers the total demand of a consumer supplied with power from several feeders, each with its own meter. The apparatus consists of the usual alternating or direct current watthour meters to which contact members are added. These contacts control an auxiliary or telemetering circuit of low current value, connected to a remotely located receiving instrument. This receiving instrument totalizes the current impulses and operates a demand register.

The principle involved in this system is that by reducing the time length of impulses the probability of superposition of impulses from different meters, and consequently the error, is reduced. This calls for contacting mechanisms for the transmitters and counters for the receivers that work with great speed. The contacts open momentarily a normally closed telemeter circuit, rather than a previous method of closing a circuit. Instead of working by current impulses, this system therefore reacts to current interruptions. The telemeter circuit connects in series all the contacts of the meters being totalized.

When using an alternating telemeter circuit the current is first rectified and filtered sufficiently to avoid frequency effects on the electromagnetic counters of the receiving instruments.

R. H. O.

Oil for the Lamps of Palestine.—(*I. & E. C.*, News Edition, Vol. 13, p. 90.) Apparently Palestine not yet has reached that stage where remarkable engineering achievements are more or less taken for granted. We read where 10 days were spent in celebrating the opening of the Mosul oil pipe line which conducts petroleum from Kerkuk in Mosul east of the Tigris to the Mediterranean Sea, a distance of more than 1200 miles. The pipe line cost 12 million pounds and the work, which was very difficult on account of the terrain, lasted two years.

The line forks at Haditha, one branch leading to Tripoli, the other to Haifa. Its annual capacity is 4 million tons and it has eleven pumping stations, three on the double line and four on the northern and southern branches respectively. This oil line passes through five countries—Iraq, Transjardania, Lebanon, Syria and Palestine.

C.

Hydraulic Giants Make Highway Cut.—(*Construction Methods*, Vol. 17, No. 4.) A water system and hydraulicking equipment of two giants was leased from the La Grange Placer Mines, Ltd., for work on a highway grading job in Trinity County, Calif., involving removal, by water spray, of about 6,000,000 cubic yards of earth. The two giants already have served their time in washing out gold-bearing gravels. The nozzles are 7 and 8 in. in diameter, respectively and are served by a main pipe line 30 in. in diameter at the upper end, 26 in. lower down, with two 18 in. branches serving them. The total operating head is 550 ft. and the 8 in. nozzle passes water at the rate of 60 sec.-ft. The water supply is from a stream feeding a regulating reservoir of 600,000 cubic feet capacity.

The large nozzle has been rated as averaging 800 cubic yards per hour, the material moved being about 10.7 per cent. of the volume of the water used. In a normal year operation is expected for at least 75 per cent. of the working season. It is thought that well over 1,000,000 cubic yards of material will be moved in 1935. Operations will probably continue for four years.

R. H. O.

Cleansing of Flue Gas.—(*Combustion*, Vol. 6, No. 10.) Excerpts of a paper by DR. J. L. PEARSON, G. NONHEBEL AND P. H. N. ULANDER presented at a joint meeting of the Institute of Fuel and the Institution of Electrical Engineers at London, Eng., provide a very good review of the problem of atmospheric pollution from cinders, fly ash and sulphur fumes in stack gases. That this is a matter of utmost concern is undeniable inasmuch as the combustion of 1,000 tons of average coal containing, say, 1.5 per cent. of sulphur, leads not only to the formation of grit, dust and possibly tarry matter, but also to the eventual formation of 45 tons of sulphuric acid, 3 to 7 tons of nitric acid (dependent upon the combustion conditions), and 0.5 ton of hydrochloric acid. In many countries today there are laws dealing with grit and dust emission from chimneys of power plants. There are also many exacting restrictions concerning the discharge of effluent into water courses near and among large urban populations. The removal of dust and acids as well as grit requires some form of wet washing. This form should not have any liquor effluent, which means a recirculating, non-effluent water system, from which the grit, dust and acids can be separated and removed as solids. Such a system is the Howden—I.C.I. system which is described. It utilizes a cheap form of alkali, lime or chalk, as the neutralizing agent and the water make-up is relatively small. A pilot plant was in continuous operation

from April, 1933, until December, 1934, except for a small fraction of this time, required for plant modifications. From numerous tests average efficiencies of removal were sulphur oxides 97 to 99 per cent., nitrogen oxides 60 to 70 per cent., hydrochloric acid 90 to 93 per cent., grit and dust from P.F. boiler 97 to 98 per cent., dust from P.F. boiler left in flue gas after having passed through a well known wetted tube deduster 90 to 93 per cent.

R. H. O.

World's Largest Tunnel for Bay Bridge.—C. W. GEIGER describes in the *Excavating Engineer* for April, 1935, this tunnel on Yerba Buena Island. It is a part of the San Francisco-Oakland Bay Bridge, which, supported by high massive piers, reaches out from San Francisco, traverses the island through what is stated to be the world's largest bore highway tunnel, and then, by means of more high piers, touches the mainland at Oakland. Its "two deck" construction provides, on the upper deck, six lanes for fast moving automobiles and, on the lower deck three lanes for trucks and two interurban-railway tracks. The tunnel is 540 ft. in length, 78 ft. wide and 67 ft. high. While massive concrete and steel walls will take up much of this great width, the completed tunnel will have a 56 foot clear roadway and a total height of about 58 ft.

This tunnel is so large that it was built by boring five pilot tunnels through the island and then breaking them down into the full bore. Two bottom headings at the base of each of the walls were put through from the west portal to the east portal of the tunnel, two more were tunneled through the side walls above these, and the fifth pilot tunnel was drilled at the crown.

R. H. O.

Aluminum Trusses and Floor for Brooklyn Bridge.—(*Engineering News Record*, Vol. 114, No. 16.) Everyone who is familiar with New York City and its environs can easily picture the famous Brooklyn Bridge. This bridge has remained in service, without substantial improvement for 52 years. More than 30 years ago the then commissioner of bridges stated "The rebuilding of the bridge has become imperative. . . ." At the present time the cross section of the bridge accommodates on one deck two rapid transit tracks, two street-car tracks and two vehicle lanes. All commercial traffic, with the exception of mail trucks is barred from the bridge. A plan for rebuilding the bridge by retaining the present anchorages, towers and main cables and suspending therefrom new stiffening trusses and a new floor fabricated from structural aluminum shapes and plates has been developed and proposed by D. B.

Steinman, consulting engineer and by the Aluminum Company of America. The new design eliminates the picturesque but inefficient diagonal stays of the old bridge. It will provide twelve 10 ft. lanes for vehicular traffic on two decks, six on each deck and it is based on unrestricted use of vehicles up to 25 ton trucks. By using aluminum the total dead load on the bridge will not be increased. The suspended structure is to be fabricated of rolled structural shapes of aluminum alloy 27ST assembled with steel rivets. The alloy has an ultimate strength of 58,000–66,000 lb. per sq. in., a minimum elastic limit of 45,000 per sq. in. and a modulus of elasticity of 10,000,000. The floor beams are spaced 15 ft. on centers and are of plate girder construction.

If the bridge is rebuilt much of the commercial traffic now using the Manhattan Bridge would logically use the Brooklyn Bridge.

R. H. O.

The Pivoted Motor Drive.—In belt-driven machinery where there are short fixed centers, the initial tension under which the belt is installed is almost never known, and is usually the result of guesswork. Belt stretch due to constant or peak loads will reduce tension of the slack side, which often results in series slippage. When this becomes evident, it is usual practice to move the motor far enough back to stop the squeak with additional tension added for good measure, involving the risk of ruined bearings and serious injury to the belt. In *Mechanical Engineering* for May 1935, R. R. Tatnall states that the most recent solution of the problem of short center drive is furnished by the pivoted-motor base in combination with a flat leather belt. In this device the motor is rigidly bolted to a pair of cast-iron or steel arms, which thus become essentially a part of the motor frame. Each arm carries a bearing, and through these a pivot shaft passes. The pivot is horizontally mounted in a cast iron or steel base, and adjustments are provided for lining up the belt laterally and for taking up belt stretch. The motor as a whole is free to swing around the pivot, its weight being supported partly by the pivot and partly by the belt. This arrangement makes it possible to utilize the weight of the motor as a means of applying tension to the belt. An adjustment in the arms allows the motor to be moved toward or away from the pivot, thus regulating the lever arm of the motor weight and giving a wide choice of belt tensions. The theory and design of the drive is explained and a graphic method of determining pivot distance suggested by P. G. Rhoads is given.

R. H. O.

A New Reflection Meter.—J. L. MICHAELSON in the *General Electric Review* for April, 1935, describes an instrument of high sensitivity and accuracy recently developed for the paper industry. Due to the increasing variety of papers and the difficulty of classification, the Institute of Paper Chemistry recently conducted a large number of tests which disclosed that the classification of book paper, with respect to quality, could best be accomplished by reflecting-power measurements in the wavelength region of 450 millimicrons. The Institute then set up specifications of book papers based on such measurements.

The instrument was developed to meet rather narrow limits for various grades of paper, to yield results which are independent of the operator's ability to judge brightness of color, to consist of a minimum number of parts and to be capable of rapid measurements with ease.

A schematic diagram shows that two phototubes are connected in series across a voltage supply. One receives light directly from a lamp, the other receives light from the same lamp after being reflected from a sample or standard and transmitted by a mechanical diaphram and a color filter. By virtue of its position, the transmission of this diaphram is directly proportional to its angular displacement. A sample to be measured is placed over the aperture provided and adjustments are made until the drop of potential across each tube is approximately equal. This is indicated by an electron tube amplifier plate current of 400 to 500 micro-amperes. Readings of the sample are then compared with readings of the standard.

In addition to its utility in the paper industry, it is reasonable to assume there are many other fields where measurements of this sort might likewise be of value. R. H. O.

New Type Radio Receiving Tubes.—(*Q.S.T.*, Vol. 19, No. 5.) A new line of metal shell radio receiving tubes which tests indicate to be of greater continued efficiency of operation than the glass-envelope types now in use, developed by General Electric and announced for appearance on the market shortly, are not only much smaller and more sturdy but also offer many improved electrical characteristics. They provide their own shielding and the metal shell is a better heat conductor and radiator than glass. They are especially advantageous in the field of short wave reception. These new tubes, cylindrical in form, have an entirely different pin arrangement, and are not interchangeable with glass tubes in the present type of radio receiver. They will make their first appearance in the new fall line of General Electric sets. R. H. O.

Melting Sleet on Transmission Lines.—Modern electric transmission lines are designed to withstand heavy ice loadings, but are unable to withstand both loading and high winds. A solution to the problem is presented by A. F. GRAMM of the Consumers Power Company in the *Electric Journal* for May, 1935. As a general rule, heavy deposits of sleet occur during a rain or mist, when temperatures are but a few degrees below freezing. This condition may continue from several hours to half a day or even longer. It is during this period that sleet can be melted to best advantage. To do this a 20,000 K.W. turbogenerator is connected directly to the line after it is taken out of service, and short circuited at the farthest end. The voltage of the generator is raised until a current of 400 to 600 amperes flows, which is usually sufficient to melt the coating. In the author's company a set of instructions for ice melting is issued so as to enable it to be done in a minimum of time.

R. H. O.

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